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MEDIUM DUTY VEHICLE EMISSION CONTROL COST EFFECTIVENESS COMPARISONS. VOLUME II. TECHNICAL DISCUSSION

AEROSPACE CORPORATION

PREPARED FOR
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VOLUME II - TECHNICAL DISCUSSION

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16. ABSTRACT

A comparative analysis was made of the emission control cost factors (expressed as dollars expended per ton of pollutant removed) of medium duty vehicles (MDVs--6000 to 14000-lb GVW), light duty vehicles (LDVs--less than 6000-lb GVW), heavy duty vehicles (HDVs--greater than 14000-lb GVW), utility power plants, and a number of other stationary sources. Mobile source emission inventories were calculated for the New York City, Los Angeles, and Phoenix-Tucson Air Quality Control Regions. The results indicate that, in the mobile source area, emission control cost factors ($/ton) in general decrease in numerical value as the vehicle weight increases; i.e., MDVs are more cost-effective than LDVs, and HDVs are more cost-effective than MDVs. This same size effect was noted in stationary source cost factor comparisons, where the cost factors decreased in numerical value as the system size (or flow rate of the product being controlled) increased. Further, stationary sources have lower control cost factors (for the same pollutant specie) than the smaller mobile sources.

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Prepared by

The Environmental Programs Group

The Aerospace Corporation
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FOREWORD

This report, prepared by The Aerospace Corporation for the Environmental Protection Agency, Division of Emission Control Technology, presents the results of a comparative analysis of the cost effectiveness of medium-duty vehicle [6, 000 to 14, 000-lb gross vehicle weight (GVW)] emission control systems.

The study results are presented in two volumes. Volume I, Executive Summary, presents a concise review of important findings and conclusions in the Highlights and Executive Summary sections. Volume II, Technical Discussion, provides a detailed discussion of each study topic and is of interest primarily to the technical specialist. In Volume II, the light-duty vehicles (LDVs -- under 6, 000-lb GVW) and medium-duty vehicles (MDVs) selected to form the basis of cost factor comparisons are characterized and delineated in Section 2. The specific emission control systems used in LDV and MDV cost calculations, the characteristic or baseline emission levels prior to incorporation of emission control systems, and the lifetime costs attributable to emission control for the LDV and MDV cases considered are presented in Section 3. A comparison and discussion of LDV and MDV cost factors (expressed as dollars expended per ton of pollutant removed) as a function of emission control system type and as a function of percent reduction in emission rate are summarized in Section 4. A brief summary is given in Section 5 of the heavy-duty vehicle (HDV -- over 14, 000-lb GVW) cases examined, including baseline emission assumptions and resultant emission control cost factors. A summary overview of emission control cost factors associated with power plants and other stationary sources is presented in Section 6. Section 7 contains a summary presentation and comparison of LDV, MDV, HDV, and stationary source emission control cost factors. A review of numerous transportation planning studies for selected air quality control regions (AQCRs), with emphasis on vehicle class distribution (LDV, MDV, and HDV) and annual mileage contributions is presented in Section 8. Section 9 includes emission inventories for LDVs, MDVs, and HDVs for the New York City, Los Angeles, and Phoenix/Tucson AQCRs. These inventories reflect the effects of various possible MDV control strategies. Appendix A contains a listing of the companies and agencies contacted in the data acquisition activity. Appendixes B through E contain backup information relative to the study.

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The following technical personnel of The Aerospace Corporation made valuable contributions to the examination and analyses performed under this contract.

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HIGHLIGHTS

An analysis was made that compared the emission control cost factors (expressed as dollars expended per ton of pollutant removed) of medium-duty vehicles[1] with other major mobile sources and with available stationary source cost data. The LDVs and HDVs, utility power plants, and a number of other stationary sources were considered in the cost factor comparisons. The results indicate that, in the mobile source area, exhaust emission control cost factors ($/ton) in general decrease in numerical value as the vehicle weight increases (i.e., MDVs are more cost-effective than LDVs and HDVs are more cost-effective than MDVs). This same size effect was noted in stationary source cost factor comparisons, where the emission control cost factors decreased in numerical value as the system size (or flow rate of the product being controlled) increased. Further, the stationary sources have lower emission control cost factors (for the same pollutant specie) than the smaller mobile sources; therefore, they are the most cost-effective in terms of emission reduction.

The absolute values of the cost factors reported herein for mobile sources are the result of (and proportional to) necessarily assumptive characteristics in three primary areas: (a) the specific emission control systems (ECSs) considered, (b) the baseline vehicle emission levels used, and (c) the method of apportioning costs between pollutant species (HC, CO, and NO_x).

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[1] Three vehicle categories are used in this report: light-duty vehicles (LDVs--under 6000-lb GVW), medium-duty vehicles (MDVs--6,000 to 14,000-lb GVW), and heavy-duty vehicles (HDVs--over 14,000-lb GVW). The distinction between LDVs and light-duty trucks (LDTs) (regulated as per Federal Register, Vol. 38, No. 151, of 7 August 1973, after the decision of the U.S. Court of Appeals) has not been considered in this report. If the general category of MDVs was defined to include LDTs, the relative impact of MDVs on emission inventories would be larger than is indicated in this report.

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With regard to the first area, seven different ECSs were considered encompassing the range of potentially available ECSs. They have considerable variance in emission reduction capability (HC, CO, and NO_x) and in overall system costs. As a consequence, they also exhibit widely varying emission control cost factors.

In the second area, the baseline emission levels (i.e., the characteristic emissions of the MDV prior to the incorporation of a given ECS) have a marked effect on the absolute level of cost factor values, since all pollutant reductions are computed as a fixed percentage of the original or baseline emission level for any given ECS. Thus, the higher the baseline emission, the greater the tons of emission reduction and consequently the lower the cost factor ($/ton) for a given ECS with fixed total costs. Two emission baselines were used to encompass the spectrum of reasonably anticipated MDV engine emission characteristics. The first (and higher) emission baseline is based on tests of 1970 to 1973 model year trucks; it is treated herein as an earlier technology baseline inasmuch as MDV engines will be undergoing further modifications to meet the more stringent requirements of the California 1975 HDV emission standards. The second (and lower) MDV emission baseline is based on extrapolations of emission characteristics exhibited by engines used in 1972 model year LDVs.

With regard to the third area, the numerical cost factor value for any given pollutant specie is directly related to the manner of allocating costs to HC, CO, and NO_x. In this study, those component, maintenance, and operating costs traceable to NO_x control were first segregated (principally EGR-related and fuel costs); all other costs were then equally divided[2] between HC and CO. If other apportionment techniques are desired, the individual cost factors developed herein can be easily recalculated. However, in terms of comparing the mobile sources, this variability in assumptive technique is not very important, since the same assumptions were made for all mobile sources considered (LDVs, MDVs, and HDVs).

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[2] More explicit allocations would require additional analysis and computations. Evaporative costs, for instance, should be allocated exclusively to HC control.

To supplement the analysis, vehicle distributions and annual mileage contributions by class (LDV, MDV, and HDV) were determined, and emission inventories were calculated for the New York City, Los Angeles, and Phoenix-Tucson Air Quality Control Regions (AQCRs). These inventories were structured to reflect the effects of various possible MDV control strategies.

The comparative analyses and supplementary examination of vehicle location, use characteristics, and emission inventories in the AQCRs of interest resulted in the following findings.

I. MOBILE SOURCE COMPARISONS

A. Effect of Emission Control System Type and Baseline Emissions

1. The cost factor variability with ECS type is wide; therefore, caution should be observed when comparing on the basis of discrete cost factors. This variability is illustrated in Table 1 for an MDV (at 6000-lb inertia test weight) as equipped with the seven different ECS considered in this study.

2. For a given baseline emission level, these cost factor variations between ECS result from the combined interactions of different emission reduction characteristics, different total system costs, and the method of apportionment of costs between HC, CO, and NO_x.

3. The higher HC and CO cost factors shown for the catalytic converter ECS in Table 1 are principally the result of converter replacements at approximately 25,000-mi intervals. Extending this replacement interval would result in commensurately lower cost factors.

4. The higher NO_x cost factors shown in Table 1 for the reduction catalyst system are due to converter replacements at 25,000-mi intervals; whereas the higher NO_x cost factors for the rich thermal reactor ECS are due to very high fuel economy losses (25 percent).

5. Two emission baselines were used in the study because MDV engines are in a state of transition, undergoing modifications to meet the

Table 1. Cost Factor Variability with Emission Control System Type and Emission Baseline--MDV at 6000-lb Inertia Test Weight

EMISSION CONTROL SYSTEM TYPE[1]	COST FACTOR, $/ton[2][3]								TOTAL LIFETIME SYSTEM COSTS, $[3][4]
	EARLIER TECHNOLOGY EMISSIONS BASELINE				1972 LDV TECHNOLOGY EMISSIONS BASELINE				
	HC	CO	NO_x	HC + CO + NO_x	HC	CO	NO_x	HC + CO + NO_x	
No. 2 -- IMPROVED CARBURETION	328	23	690	103	978	67	1282	291	415
No. 3 -- OXIDATION CATALYST	553	48	690	148	1660	141	1282	342	871
No. 4 -- OXIDATION AND REDUCTION CATALYSTS	553	48	1260	215	1660	141	2340	600	1682
No. 5 -- ELECTRONIC FUEL INJECTION PLUS TRICOMPONENT CATALYST	469	40	364	106	1403	120	675	295	825
No. 6 -- LEAN THERMAL REACTOR	195	13	655	88	585	40	1220	249	518
No. 7 -- RICH THERMAL REACTOR	137	17	1400	199	412	52	2600	555	1267
No. 8 -- ADVANCED LEAN CARBURETION	298	22	288	65	892	67	534	185	414

(1) THE IDENTIFICATION NUMBER CORRESPONDS TO THAT ASSIGNED BY CALSPAN CORPORATION IN REPORT ZP-5223-k-1; THE NAME REFERS TO THE PRINCIPAL OR DIFFERENTIATING FEATURE -- ALL SYSTEMS HAVE EGR

SOME OF THE VALUES PRESENTED IN THIS TABLE ARE BASED ON INCOMPLETE DATA AND SHOULD NOT BE TAKEN AS CONCLUSIVE. DATA FOR SYSTEMS Nos. 2 AND 3 ARE RELATIVELY BETTER DOCUMENTED

THIS TABLE ASSUMES, IN ALL CASES, A DURABILITY FACTOR OF 1

(2) COST FACTOR = DOLLARS EXPENDED PER TON OF POLLUTANT REMOVED OVER VEHICLE LIFETIME

(3) CATALYSTS WERE CHANGED AT 25,000 mi INTERVALS

(4) INITIAL PLUS MAINTENANCE PLUS FUEL COSTS; COSTS ARE ASSUMED TO BE INDEPENDENT OF BASELINE EMISSION LEVEL ASSUMPTIONS

increasingly lower levels of emission standards as prescribed by the federal government and the State of California for engines used in vehicles over 6000-lb GVW. These two baselines were selected to encompass the spectrum of reasonably anticipated MDV engine emission characteristics prior to the addition of the seven specific ECSs evaluated; they are depicted in Figure 1 for HC. The CO and NO_x baselines have different absolute levels, but their slopes are similar to those shown for HC.

6. Cost factors based on the 1972 LDV technology emissions baseline are from two to three times higher than similar cost factors based on the earlier (1970 to 1973 MDVs) technology emissions baseline (Table 1). This reflects the fact that the 1972 LDV technology emissions, prior to adding any of the seven ECS, are two to three times lower than the earlier technology baseline emissions, thus giving lower values for emission reductions over the vehicle lifetime. Since the total system costs are assumed to be independent of the baseline emission levels, the cost factors vary directly and inversely with baseline emission values.

B. Effect of Vehicle Weight

1. As illustrated in Table 2, both HC and CO cost factors decrease as the vehicle inertia test weight increases. Although Table 2 is based on a single ECS (1975-type passenger car oxidation catalyst system) and the 1972 LDV technology emission baseline, similar trends with vehicle weight occur for all ECS examined, and for both emission baselines examined.

2. This result of decreasing HC and CO cost factor with increasing vehicle weight results from the fact that the baseline emissions increase in level as the vehicle weight increases (shown in Figure 1). Since pollutant reductions for a given ECS were computed as a fixed percentage of the baseline emission level, as the vehicle weight increases the tons of emission reduction increase commensurately, thus giving lower cost factors ($/ton), since the HC and CO related costs were independent of vehicle weight for the cases considered in Table 2.

3. On the other hand, NO_x cost factor variation with vehicle weight is strongly influenced by the baseline emission level selected for comparison. As shown in Table 2, based on the 1972 LDV technology baseline, the NO_x cost factors increase in numerical value as vehicle weight increases until approximately 11,000 lb, where the trend is reversed. This occurs because all fuel economy losses were attributed to NO_x control. The variation of fuel economy with vehicle weight used in the analysis has a continually decreasing rate of loss of fuel economy with increasing weight (e.g., less change in fuel economy

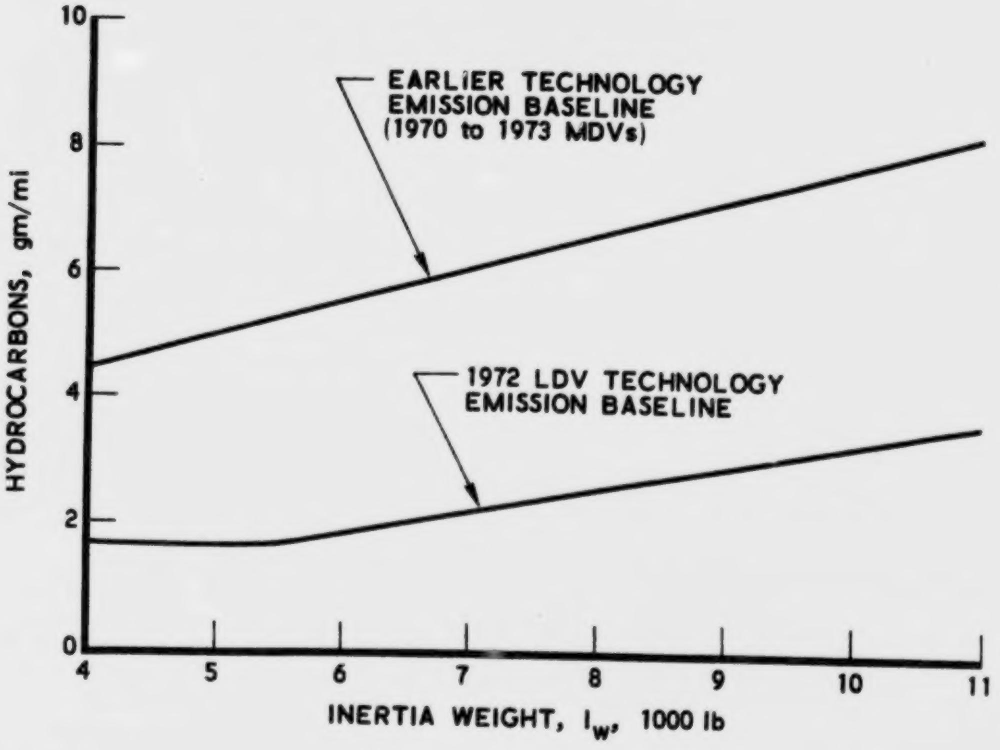

Figure 1. Variation in Baseline Emission Level with Vehicle Test Weight--HC Emissions

from 13,000 to 14,000 lb than from 9,000 to 10,000 lb). The interaction of the fuel economy characteristic line and the NO_x baseline emission level slope thus results in the NO_x cost factor shown in Table 2.

2. However, when comparing with the earlier technology NO_x baseline emission (Table 2), the higher absolute value and steeper slope of the NO_x emission line overrides the fuel economy characteristic noted above and results in NO_x cost factor variations which decrease as vehicle weight increases, as for the case of HC and CO mentioned previously.

C. Gasoline Versus Diesel Powered HDVs

1. Comparison of gasoline- and diesel-powered HDVs on a simple cost factor basis can be misleading because of their inherently different

Table 2. Cost Factor Variability with Vehicle Weight--1972 LDV Technology Emission Baseline (Oxidation Catalyst and EGR Control System)

VEHICLE INERTIA TEST WEIGHT, lb	EMISSION CONTROL COST FACTOR, $/ton		
	HC	CO	NO_x
4,500	1810	180	1215 (1117)
6,000	1660	141	1282 (690)
9,000	1060	60	1350 (643)
11,000	850	43	1360 (617)
14,000	654	30	1300 (560)

VALUES IN PARENTHESES ARE BASED ON EARLIER TECHNOLOGY NO_x EMISSIONS BASELINE

fuel economy characteristics. If the diesel fuel economy advantage is not considered in the cost equation, diesel-powered HDV HC and CO cost factors are in the same general range as those for a gasoline-powered HDV with an oxidation catalyst plus EGR ECS, $243/ton and $20/ton, respectively. If the diesel fuel economy advantage is included, diesel HC and CO cost factors become negative, -$921/ton and -$76/ton, respectively. With EGR, the direct-injection diesel-powered HDV has a NO_x cost factor (approximately $210/ton) in the same general range as gasoline-powered HDV NO_x cost factors.

II. MOBILE AND STATIONARY SOURCE COST FACTOR COMPARISONS

1. Mobile source NO_x control cost factors are appreciably higher than stationary source NO_x cost factors, with typical values of $500 to $1300/ton. Comparable stationary source NO_x cost factors are generally less than $100/ton.

2. Mobile source CO control cost factors, although relatively low in numerical value ($30 to $200/ton), are still considerably higher than the single value of less than $2/ton obtained for the stationary source CO boiler.

3. Mobile source HC control cost factors ($400 to $1800/ton) are much higher than cost factors for stationary source bulk treatment methods for HC control (e.g., storage tanks, bulk loading facilities, and service station holding tank methods with cost factors of $15 to $119/ton). However, service station refueling HC control systems have cost factors in the same general range as mobile source values ($200 to $1400/ton).

4. In all cases permitting comparisons, mobile or stationary source, it is observed that emission control cost factors ($/ton) decrease in value as the system or vehicle size and/or throughput (flow rate of product being controlled) increases. Size effects alone indicate that, in general, stationary source emission control is more cost-effective than mobile source emission control.

III. VEHICLE LOCATION CHARACTERISTICS

1. Recent vehicle location surveys for three AQCRs (New York City, Los Angeles, Phoenix-Tucson) depict the characteristic that trucks decrease as a percentage of total vehicles as the area involved increases in population density (Table 3). This trend is reversed in very small, highly populated, traffic-congested areas such as Manhattan, New York. Here, the percent of trucks increases, apparently because of the need to provide goods and services for the many people in the area and the concurrent difficulty of owning, storing, and/or operating passenger cars in such areas.

Table 3. Vehicle Registration Breakdown by Location--1 July 1972

Based on 1 July 1972 cars in operation and trucks in operation surveys by R. L. Polk Company.

PARAMETER	LOCATIONS					
	NATION	NEW YORK CITY AREAS			SOUTH COAST AIR BASIN AQCR (Los Angeles)	PHOENIX-TUCSON AQCR
		NEW YORK CITY AQCR	NEW YORK CITY (Five Boroughs)	MANHATTAN (New York County)		
TOTAL NUMBER OF VEHICLES	106,211,895	6,637,845	1,772,355	220,614	5,802,658	941,697
PERCENT AUTOMOBILES	81.38	92.1	93.47	86.09	83.75	75.91
PERCENT TRUCKS	18.62	7.91	6.53	13.91	16.25	24.09
PERCENT OF TOTAL TRUCKS BY WEIGHT CLASS						
0 TO 6,000-lb GVW	64.79	51.20	40.22	32.74	59.55	73.40
6,000 TO 14,000-lb GVW	19.09	18.89	19.91	18.86	29.70	18.50
OVER 14,000-lb GVW	16.12	29.91	39.87	48.40	10.75	8.10

2. The distribution of LDTs appears to vary uniformly and inversely with population density.

3. Except for the Los Angeles AQCR, the MDV distribution as percent of total trucks appears not to be strongly affected by population density, but rather to remain near the national average of approximately 19 percent. In the Los Angeles case, where the MDV percentage of total trucks is approximately 30 percent, this anomaly may be the result of the widespread use of heavier campers and motor homes for recreational purposes.

4. The HDVs increase in distribution as percent of total trucks in accordance with increasing population density. This may be the logical result of the need for heavy trucks to move goods into the densely populated areas in accordance with the number of inhabitants involved.

IV. EMISSION INVENTORY EFFECTS

1. Four cases or possible strategies for MDV and HDV emission control were examined to calculate emission inventories from 1970 to 1990 for the three AQCRs considered. The principal features of these emission control strategies and their corresponding LDV, MDV, and HDV emission levels are summarized in Table 4.

2. With no further emission control beyond the presently established LDV regulations (including the 1976 LDV regulations) and the 1974 Federal HDV standards (for all vehicles over 6000-lb GVW), emissions in the 1985 to 1990 period are reduced to approximately 25 to 30 percent of 1970 levels. This is illustrated for the HC inventory in the New York City AQCR as Strategy No. 1 in Figure 2. Similar trends occur for CO and NO_x, and for the Los Angeles and Phoenix-Tucson AQCRs.

3. Implementation of MDV and HDV emission standards equivalent to the California 1975 HDV standards in the 1975 to 1977 period (Strategy No. 2) results in a further sizeable reduction for all three pollutants. This is illustrated in Figure 2 where the 1990 HC inventory is approximately 15 percent of the 1970 value. This assumes, although it may well not be the case, that emission reductions for the current nine mode HDV engine dynomometer procedure are representative of actual vehicle emission reductions.

4. The addition of oxidation catalysts (in 1977 to 1979) and reduction catalysts (in 1980 to 1982) to MDVs has relatively little effect on total emissions by 1990; this is illustrated as Strategies No. 3 and 4, respectively, in Figure 2 for HC. This minimal effect occurs because only MDVs (and not HDVs) are equipped with the catalysts,

Table 4. Control Strategy Emission Levels

STRATEGY NUMBER	EMISSION LEVEL ASSUMPTION								
	LDVs	MDVs				HDVs			
		BASIC FEATURE	EMISSION LEVEL,(1) gm/mi			BASIC FEATURE	EMISSION LEVEL, (1) gm/mi		
			HC	CO	NO_x		HC	CO	NO_x
1	CURRENT FEDERAL LDV REGULATIONS (including the 1976 LDV regulation), ALL FOUR STRATEGIES	1974 FEDERAL HDV STANDARDS	4.25	62.08	6.57	1974 FEDERAL HDV STANDARDS	17.9	179	12.6
2(2)		1975 CALIFORNIA HDV STANDARDS	1.33	38.08	2.06	1975 CALIFORNIA HDV STANDARDS	5.6	112	3.94
3(3)(4)		OXIDATION CATALYST ADDED	0.40	4.20	2.06	1975 CALIFORNIA HDV STANDARDS	5.6	112	3.94
4(4)(5)		REDUCTION CATALYST ADDED	0.40	4.20	0.45	1975 CALIFORNIA HDV STANDARDS	5.6	112	3.94

(1) VALUES IN gm/mi EITHER BASED ON TEST RESULTS, ON CONVERSION FROM gm/bhp-hr STANDARDS, OR ON ESTIMATES OF CATALYTIC CONVERTER EFFICIENCY

(2) IMPLEMENTED IN CALIFORNIA IN 1975; REST OF UNITED STATES IN 1977

(3) IMPLEMENTED IN CALIFORNIA IN 1977; REST OF UNITED STATES IN 1979

(4) ONLY MDVs ARE REGULATED TO LOWER LEVELS IN STRATEGIES 3 AND 4, i.e. HDVs REMAIN AT 1975 CALIFORNIA HDV STANDARD LEVELS

(5) IMPLEMENTED IN CALIFORNIA IN 1980; REST OF UNITED STATES IN 1982

and they represent a relatively small percent of the total number of vehicles in an AQCR (e.g., MDVs are only 1.5 percent of total vehicles in New York City AQCR), and contribute only a small amount of the total VMT (e.g., MDVs contribute 3.15 percent of the total daily VMT in the New York City AQCR).

5. The various control strategies examined do have a marked effect on the relative percentage contributions of the LDV, MDV, and HDV vehicle classes (shown in Figure 3 and Table 5 for HC in the New York City AQCR). Under Strategy No. 1, HDVs would be contributing as much emissions as LDVs by 1985. Strategy No. 2 would appreciably reduce the HDV contribution, but it would still be approximately three times higher in 1990 than in 1970. Strategies No. 3 and 4 do not further reduce HDV emission levels (apply only to MDV

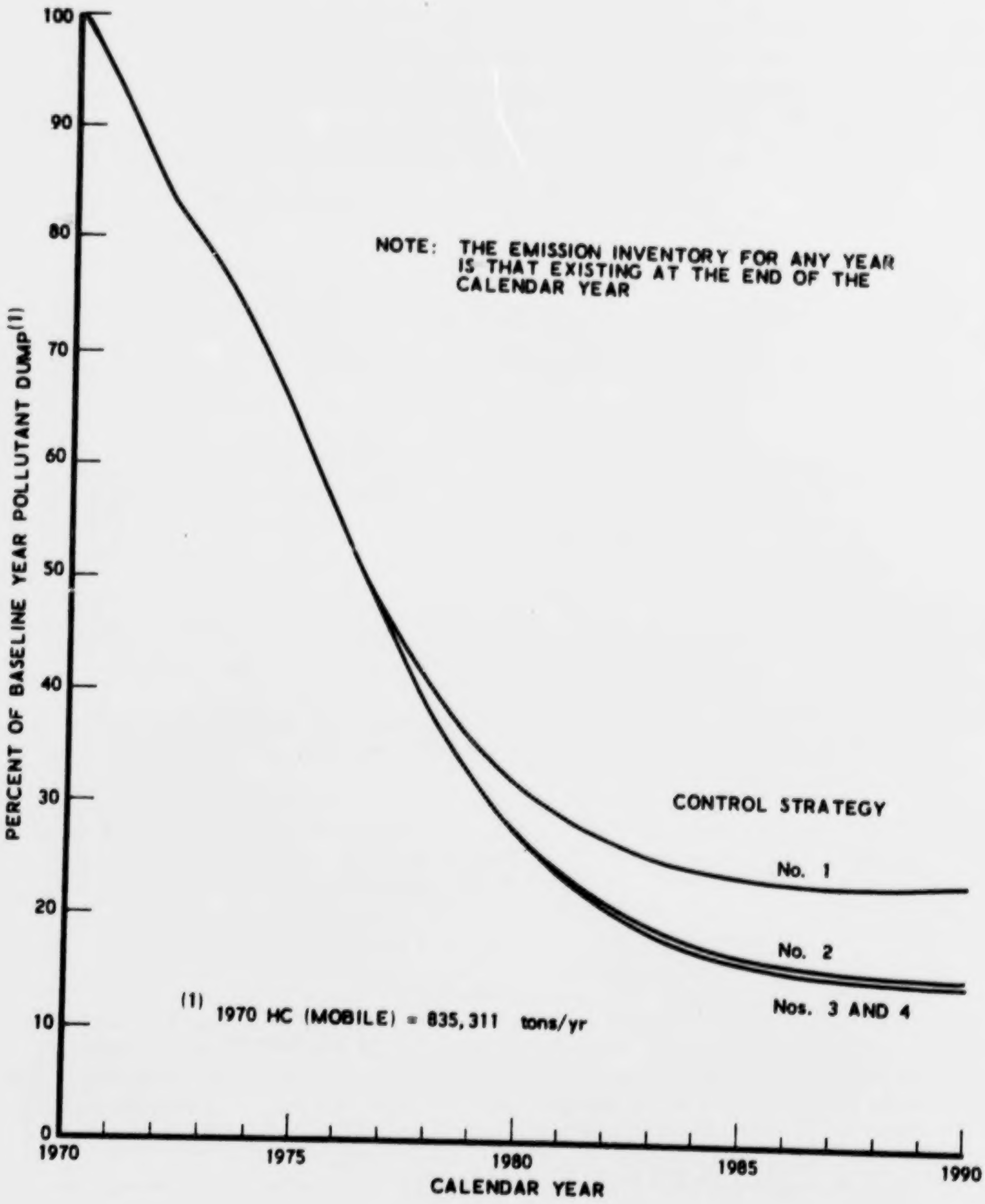

Figure 2. New York City AQCR Mobile Source HC Inventory (Determined Using Anticipated Normal Growth Rates)

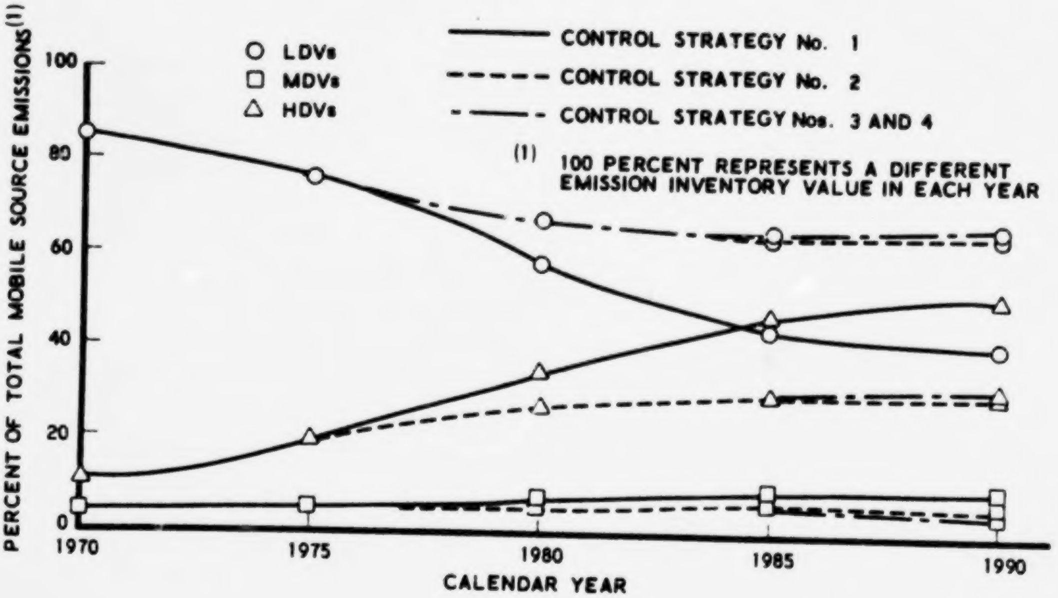

Figure 3. New York AQCR--HC Percentage Contribution of Vehicle Classes (Normal Growth Rates)

emission levels); they would have to be expanded to include HDVs to significantly alter the HDV percentage contribution.

6. In the case of MDVs, their percentage contribution rises steadily from 1970 to 1990 under Strategy No. 1, increasing from 4 to 9 percent as shown in Table 5. This is about 23 percent of the LDV emissions in 1990. Strategy No. 2 reduces 1990 MDV contributions to approximately 6 percent, while Strategies No. 3 and 4 (oxidizing and reducing catalyst in MDVs only) reduce 1990 MDV values to slightly below (approximately 3 percent) 1970 percentage levels.

7 Combined MDV and HDV emissions (vehicles over 6000-lb GVW) exceed LDV HC emissions by approximately 50 percent in 1990 under Strategy No. 1 (Table 5). Under all other strategies examined, the combined percentage of MDV and HDV emissions in 1990 are approximately two times their 1970 percentage levels.

With regard to mobile source emission control, the emission control cost factors clearly illustrate that MDV emission control is cost-effective when compared with LDVs equipped with similar control systems.

Table 5. New York City AQCR Mobile Source HC Distribution by Vehicle Class--1970 and 1990

CONTROL STRATEGY NUMBER	PERCENT OF TOTAL MOBILE SOURCE HC INVENTORY							
	1970				1990			
	LDV	MDV	HDV	MDV AND HDV	LDV	MDV	HDV	MDV AND HDV
1	85	4	11	15	40	9	51	60
2(1)	ALL FOUR STRATEGIES HAVE SAME 1970 BASELINE VALUES			15	64	6	30	36
3(2)				15	66	3	31	34
4(3)				15	66	3	31	34

(1) IMPLEMENTED IN 1977 IN NEW YORK CITY AQCR

(2) IMPLEMENTED IN 1979 IN NEW YORK CITY AQCR

(3) IMPLEMENTED IN 1982 IN NEW YORK CITY AQCR

Further, it is also clear that HDV emission control is even more cost-effective, on a dollars per ton of pollutant removed basis.

Currently, the MDV category is a relatively small contributor of emissions. However, if no additional control beyond that regulated for 1974 is added to MDVs, these vehicles would be large emission contributors. For instance, in the New York City AQCR, MDVs in 1970 emitted an amount of HC which was about 5 percent of the amount emitted by LDVs; however, in 1990 the percentage would grow to about 23 percent of the amount emitted by LDVs.

The HDV emissions are a significant portion of the total emission inventory (e.g., approximately 36 percent of HC inventory in New York

City AQCR in 1990) if emission standards no more severe than the 1975 California HDV standards are implemented. If current Federal 1974 HDV standards persist to 1990, the HDV HC percentage contribution in the New York City AQCR would be approximately 60 percent. Therefore, it would appear that advanced HDV emission control strategies would be also most fruitful to pursue, both on the basis of cost effectiveness and emission inventory reduction potential.

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SECTION 1

INTRODUCTION

1.1 BACKGROUND, OBJECTIVES, AND SCOPE

Motor vehicles over 6000 lb gross vehicle weight (GVW) are currently regulated as heavy-duty vehicles (HDVs) with regard to exhaust emission control. The HDV engine manufacturers are required to certification-test the engine only (plus any associated emission control equipment) in accordance with a prescribed engine dynamometer test procedure. The HDV, *per se*, is not certification-tested as a complete vehicle unit, as are light-duty vehicles (LDVs) (less than 6000-lb GVW).[1]

These dynamometer tests are at steady-load conditions and do not include transient load effects. Surveillance tests of HDVs in on-the-road operation indicate extreme vehicle-to-vehicle variability when attempting to correlate on-the-road emissions with engine dynamometer test results. Because of this correlation difficulty, it would be desirable, in the absence of feasibility restrictions, to certification-test as many HDV models as possible over representative vehicle transient test cycles rather than continuing with the current engine-only, fixed-mode tests.

The group of HDVs between 6,000 and 14,000-lb GVW has characteristics that appear to permit certification testing of the complete vehicle over the same Urban Dynamometer Driving Schedule and using the same constant volume sampling (CVS) mass measurement techniques used for LDV certification testing. This group of vehicles (tentatively 6,000 to 14,000-lb GVW) are termed medium-duty vehicles (MDVs). Test programs were implemented by EPA to characterize the MDV emission levels when tested on the Federal LDV CVS procedure. In addition, EPA has funded studies to determine: feasible exhaust emission reductions for MDVs as a function of lead times required and the cost and performance penalties (if any) associated with various levels of emission reduction.

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[1] See, for example, "New Motor Vehicles and New Motor Vehicle Engines -- Control of Air Pollution," *Federal Register*, Vol. 37, No. 221, 24279, 15 November 1972.

This study was initiated with two objectives: (a) to identify, quantify, and summarize those factors impacting on the cost-effectiveness of MDV emission standards and (b) to present analyses and significant results to EPA for their evaluation and consideration in future courses of action with regard to MDV emission standards.

In meeting these objectives, evaluations were to be structured and directed to identifying critical factors in the key areas of:

a. Determining MDV emission control cost effects

b. Comparing MDV cost factors with those associated with controlling other emission sources

c. Estimating the impact of MDV emission control on the air quality of metropolitan areas with severe pollution problems.

With regard to cost factor comparisons, the study scope was restricted to comparisons of MDVs with LDVs, HDVs, and various stationary sources. In the area of air quality impact, the study scope was confined to the determination of mobile source emission inventories in the following Air Quality Control Regions (AQCRs):

a. New York City

b. South Coast Air Basin (Los Angeles, California)

c. Phoenix/Tucson

1.2 ACQUISITION OF RELEVANT DATA

Nearly all data reported herein were acquired and developed between 1 May and 20 July 1973 from technical reports and technical discussions held with representatives of companies engaged in MDV-related activities and with agencies responsible for local transportation planning studies or regional air quality criteria. Table 1-1 summarizes the companies

Table 1-1. Data Sources

Cost and Emissions Effects	Air Quality Effects
Calspan Corporation MDV Report[a]	Tri-state Planning Commission
Motor Vehicle Manufacturers Association (MVMA) Data	TRW Systems/GCA Corporation (TRW/GCA) Studies
Southwest Research Institute (SwRI)[b]	State Implementation Plans
Automotive Environmental Systems, Inc. (AESI)[b]	Los Angeles Regional Transportation Study (LARTS)
Research Triangle Institute (RTI)	Tucson Area Transportation Planning Agency
EPA/Ann Arbor	EPA/Research Triangle Park/Ann Arbor
Ethyl Corporation	Wilbur Smith and Associates/Heavy Duty Truck Studies in New York City and Los Angeles
	Local Air Pollution Control Agencies

[a] The Calspan Corporation performed a technical evaluation of various emission control systems (ECSs).

[b] The SwRI and AESI participated in the recent EPA MDV emission level characterization test program.

and agencies from whom data were acquired. Appendix A contains a listing of significant visits or communications, including date of contact, company/agency contacted, and personnel involved.

To provide a consistent data base for vehicle population location and effects determination, truck registration data as a function of GVW were obtained from the R. L. Polk Company for the AQCRs of interest. Similar registration data for passenger cars were available from a study recently completed for EPA by Aerospace.[2] Many other documents of related interest were reviewed during the study and are referenced herein where they are of particular relevance.

1.3 ORGANIZATION OF THIS REPORT

Section 2 identifies the LDVs and MDVs selected to form the basis of cost factor comparisons. [Cost factor is defined as the dollars expended per ton of pollutant removed over the vehicle and/or control system lifetime ($/ton).] It also correlates inertia test weight and GVW in the MDV weight range and identifies fuel consumption variability with inertia test weight as used in succeeding cost calculations.

Section 3 contains delineation and description of ECSs used in LDV and MDV cost calculations, the rationale for and the selection of baseline MDV emission levels prior to the incorporation of specific ECS, and the development of lifetime costs attributable to emission control for the LDV and MDV cases considered.

The MDV and LDV cost factors are compared in Section 4 as a function of ECS type and as a function of percent reduction in emission rate. Also illustrated are correlations of MDV and LDV cost factors based on emission rate and with selected ECS types used to shape the correlation curves. Section 5 includes a brief summary of HDV cases examined, including baseline emission assumptions and resultant emission control costs. The cost factor comparisons shown also include the effect of diesel engine usage.

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[2] Examination of Issues Related to Two-Car Regional Emission Control Strategies, Report ATR-73(7324)-1, Vols. I and II, The Aerospace Corporation, El Segundo, California (30 April 1973).

Section 6 includes an overview of the cost factors associated with emission control in power plants and other stationary sources. Also illustrated is the effect of power plant size on emission control cost factor. Section 7 contains a brief summary and comparison of LDV, MDV, HDV, and stationary source emission control cost factors.

Section 8 reviews numerous transportation planning studies for the AQCRs of interest with emphasis on vehicle miles traveled (VMT) distribution by vehicle class (LDV, MDV, and HDV). It also includes the results of a recent R. L. Polk Company truck registration survey as a function of GVW classification. Section 9 includes emission inventories for LDVs, MDVs, and HDVs for the New York City, Los Angeles, and Phoenix/Tucson AQCRs; the effects of various MDV control strategies are illustrated.

SECTION 2

SELECTION OF MDVs AND LDVs FOR COST FACTOR COMPARISONS

The MDV inertia test weight as a function of GVW characteristics and fuel economy as a function of weight characteristics were examined to select representative MDVs for comparison with LDVs on a cost-effectiveness basis. This section summarizes the significant results of these examinations and the resultant selection of comparison cases.

2.1 GROSS VEHICLE WEIGHT AND TEST WEIGHT CORRELATIONS

There is extreme variability in truck curb weight or unloaded weight W_c within a single GVW category because of the diverse number of truck types, models, etc. Coupled with the curb weight variability is the variability in payload actually carried. For example, many light pickup trucks may be used primarily for personal transporation, with useful payload other than passengers only occasionally being transported. Conversely, trucks principally in commercial use would be expected to be used for transporting some level of useful payload, either as cargo (e.g., parcel delivery trucks) or as parts, tools, and equipment (e.g., utility service trucks).

One data source for GVW and test weight correlation purposes is the MDV baseline emission characterization program recently conducted by EPA. In this program, 175 MDVs were tested by the Federal CVS procedure. Fifty vehicles were tested by SwRI, 50 vehicles were tested by AESI, and 75 vehicles were tested by the EPA Motor Vehicle Emissions Laboratory, Ann Arbor, Michigan. The payload incorporated in each vehicle tested was prescribed by the following schedule based on the difference between GVW and W_c. Therefore, the inertia test weight I_w was the curb weight plus the payload added. Appendix B summarizes significant test parameters and emissions results for a majority of the vehicles tested.

GVW - W_c, lb	Payload Added to W_c, lb
less than 2000	500
2000 to 4000	1000
greater than 4000	1500

Figure 2-1 illustrates the variability of I_w as a function of GVW for trucks and motor homes based on Appendix B data. Also shown is the truck correlation selected for gross sizing purposes in the present study. Although the number of motor homes represented is not large, the value of I_w = 0.85 GVW was considered sufficiently accurate for gross sizing purposes.

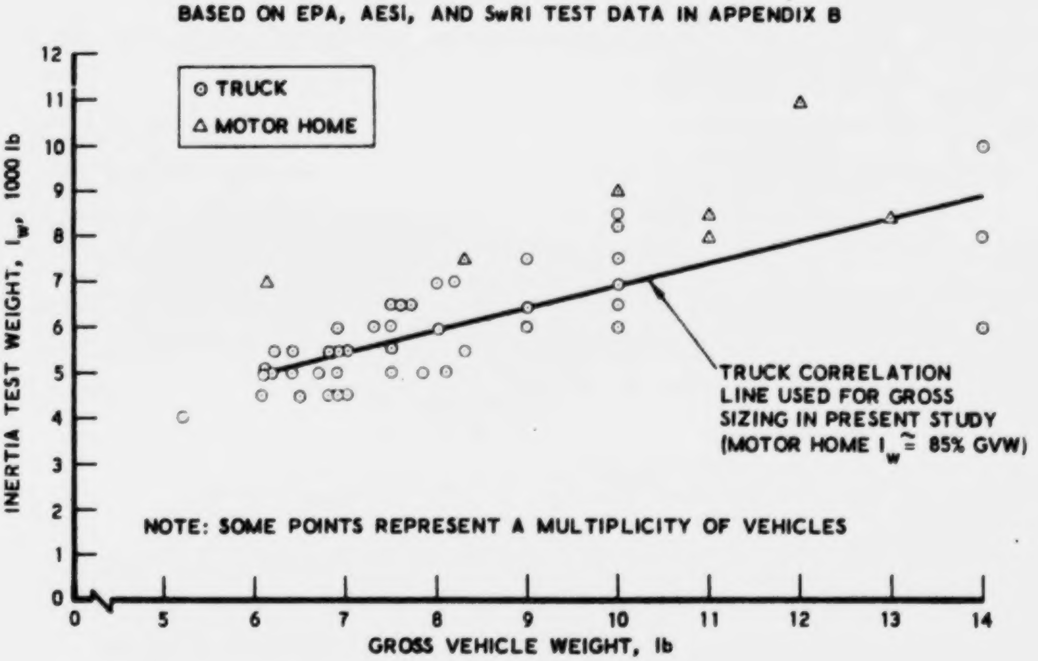

Figure 2-1. Correlation of MDV GVW and I_w

Another source of GVW and test weight correlation is the truck exhaust emission analysis and mode cycle development study performed by the Ethyl Corporation for the U. S. Public Health Service (Division of Air Pollution) in 1967 (Ref. 2-1). Most of these trucks were tested at one-half their payload capacity. Figure 2-2 shows the resultant correlation of GVW and test weight W_{test} on the one-half payload capacity basis. It also shows the MDV I_w as a function of GVW correlation selected in Figure 2-1 on the basis of the more recent MDV test program and payload assumptions. The correlations are nearly the same in the GVW range of interest (6,000 to 14,000 lb).

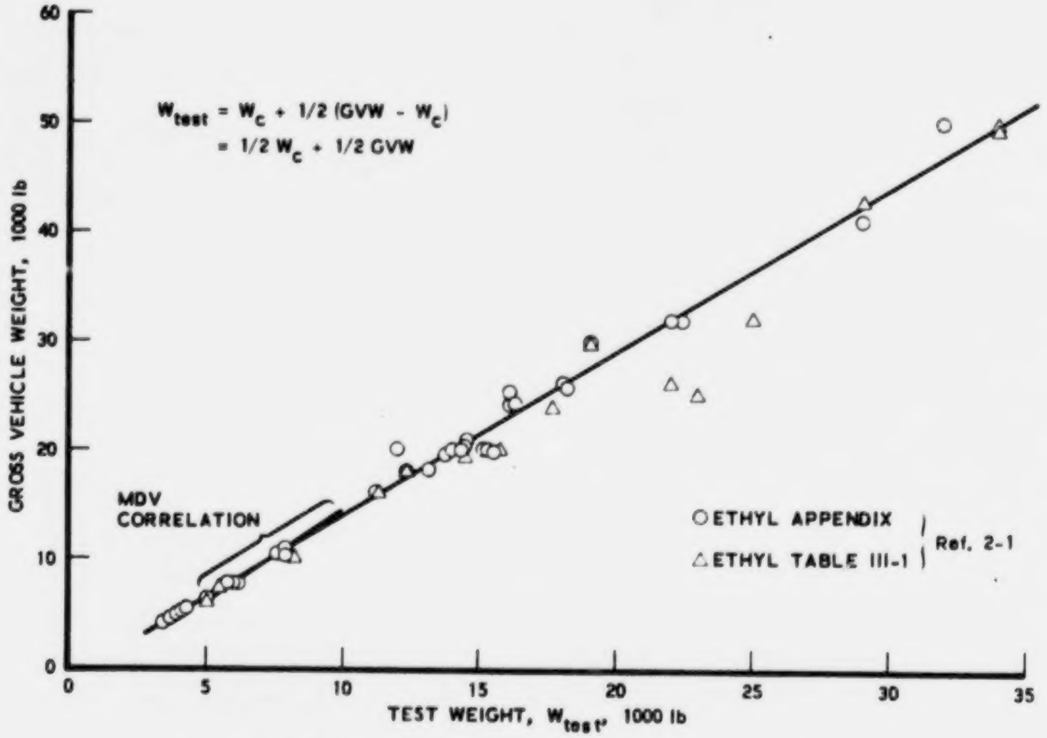

Figure 2-2. Correlation of GVW and Test Weight

2.2 FUEL ECONOMY CHARACTERISTICS

The variation of fuel economy with vehicle weight is an important parameter when determining cost differences between vehicle classes. Such data for passenger cars driven over the Federal Driving Cycle (FDC) are available from Ref. 2-2, and are illustrated in Figure 2-3. Similar data for MDVs with 350-cu-in. displacement (CID) engines are presented in a recent study made by Calspan Corporation (Ref. 2-3). As shown in Figure 2-3, the Calspan MDV fuel economy data are in reasonable agreement with the EPA passenger car data in the region of overlap (approximately 5000 lb I_w). Also, the Calspan data exhibit a decreasing rate of loss of fuel economy with increasing test weight, which would be expected since trucks generally have an increasingly higher number of gear-box speed changes with increasing GVW. This characteristic tends to offset to some extent the inverse variance of fuel economy with vehicle weight.

For the present study, the 350-CID engine fuel economy line in Figure 2-3 was used for all cases of comparison of LDVs and MDVs. The single engine size of 350-CID was selected because it is in popular use in all vehicle classes: LDV, MDV, and HDV.

2.3 CASES FOR COST FACTOR COMPARISONS

The individual cases or characteristic vehicles selected for examination of emission control cost factors are shown in Table 2-1. A single vehicle, weighing 4500 lb loaded, was selected to represent the LDV class. As noted in the table, based on later-acquired data, this 4500-lb value is somewhat lower than the sales-weighted average value of I_w = 4800 lb for the 1972 model standard-size car; however, it is somewhat higher than the I_w sales-weighted average of 3945 lb for all 1972 passenger cars (Ref. 2-4). Thus, the choice of 4500 lb appears to be a reasonable selection for comparison purposes.

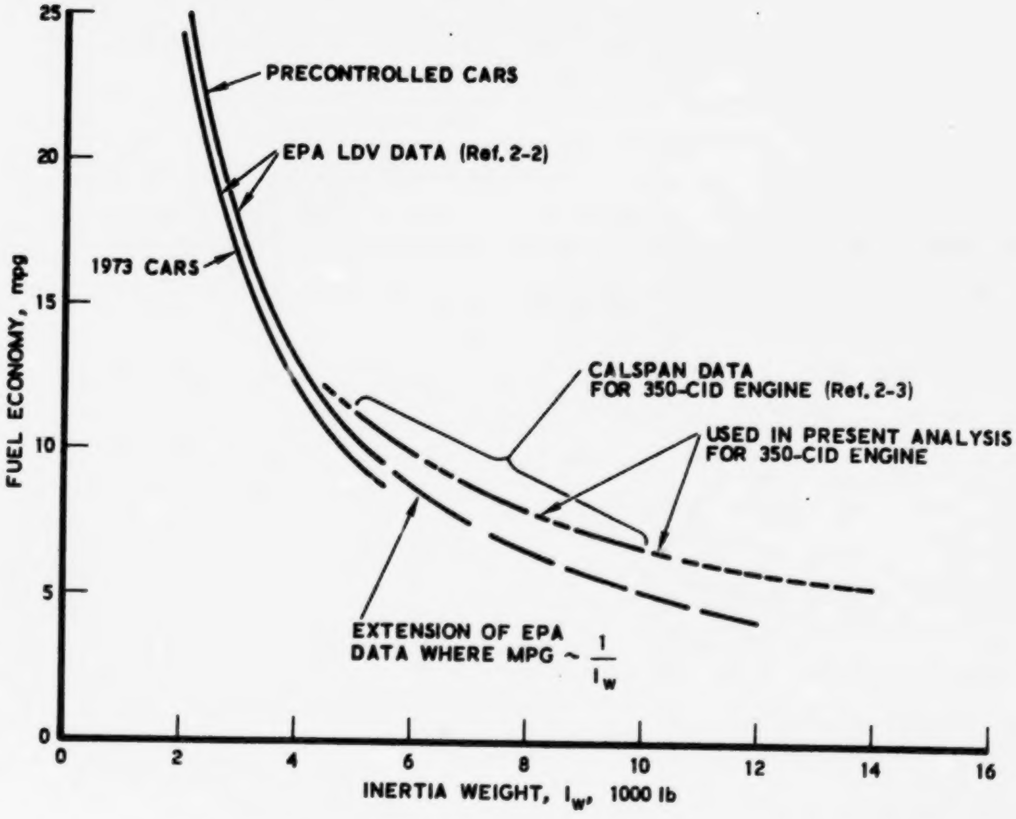

Figure 2-3. Fuel Economy Characteristics

In the MDV class, four vehicles were selected:

a. Truck A -- representing the average GVW (8000 lb) of the 6,000 to 10,000- lb GVW class

b. Truck B -- representing the average GVW (12,000 lb) of the 10,000 to 14,000- lb GVW class

c. Motor Home -- at 13,000-lb GVW representing the class of larger motor homes becoming increasingly popular in recent years

d. Truck C -- at 14,000-lb I_w representing a fully-loaded upper GVW weight class MDV; at this I_w value it also represents partially-loaded lower GVW range HDVs (e.g., 16,000 to 19,500-lb GVW HDV class, etc.)

Table 2-1. Cases for Emission Control
Cost Factor Comparisons

CHARACTERISTICS	VEHICLES				
	LDV	MDV			
		TRUCK 'A'	TRUCK 'B'	MOTOR HOME	TRUCK 'C'
GROSS VEHICLE WEIGHT, lb	<6000	8000 (ave.) of 6-10,000)	12,000 (ave. of 10-14,000)	13,000	14,000
GCW + f(GVW-GCW), lb	4500	6200	8700	11,050	14,000 (fully loaded)
I_w, lb	4500(1)	6000	9000	11,000	14,000(2)
ENGINE, CID	350(1)	350	350	350	350
FUEL ECONOMY, mpg (over Federal Driving Cycle)	12.0	10.0	7.25	6.2	5.4

(1) SALES-WEIGHTED VALUES FOR 1972 STANDARD SIZE CAR ARE: I_w = 4800 lb; CID = 371.4 cu in. (Ref. 2-4)

(2) REPRESENTS A FULLY-LOADED MDV OR A PARTIALLY-LOADED HDV

The loaded or test weight of trucks A and B and the motor home were determined from the GVW as a function of I_w relationship of Figure 2-1. The I_w value shown in Table 2-1 represents rounding off the loaded weight to the nearest 1000 lb.

A single engine size, 350-CID, was selected for all five vehicles to remove instances of engine-size-related variability in the cost factor calculations. This engine size range is one of the most frequently used in the MDV class (Ref. 2-3). In the LDV class, the sales-weighted average engine displacement for the 1972 standard-size passenger car was 371.4 cu in. (Ref. 2-4); for all domestic 1972 passenger cars the sales-weighted average engine displacement was 319 cu in. (Ref. 2-4). Therefore, the choice of 350-CID for the LDV class is also a reasonable selection.

Since fuel economy characteristics (mpg) for the five vehicles in Table 2-1 are based on the 350-CID line of Figure 2-3, they are based on a consistently varying fuel economy as a function of I_w characteristic.

In summary, the cases selected (Table 2-1) represent reasonable vehicles for the LDV class and the MDV GVW spectrum (6,000 to 14,000 lb). In addition, the motor home (I_w = 11,000 lb) and truck C (I_w = 14,000 lb) may also characterize a portion of the HDV class (GVW greater than 14,000 lb) at small or intermediate payload values. The I_w versus GVW correlations used to grossly size these vehicles (Figures 2-1 and 2-2) are of course not exact because of the previously mentioned wide variability in truck curb weights. However, they should be more than adequate to describe the candidate cases for cost comparison purposes.

REFERENCES

2-1 Exhaust Emission Analysis and Mode Cycle Development for Gasoline-powered Trucks, Report GR 67-41, The Ethyl Corporation, Detroit, Michigan (September 1967).

2-2 Fuel Economy and Emission Control, U.S. Environmental Protection Agency, Office of Air and Water Programs, Mobile Source Pollution Control Program (November 1972).

2-3 Research Study Involving (A) Technical Evaluation of Emission Control Approaches and (B) Economics of Emission Reduction Requirements for Vehicles Between 6000 and 14,000 Pounds GVW, Report ZP-5223-K-1, Calspan Corporation, Buffalo, New York (31 May 1973).

2-4 Passenger Car Weight Trend Analysis, The Aerospace Corporation, El Segundo, California (to be published).

SECTION 3

CANDIDATE EMISSION CONTROL SYSTEMS AND BASELINE EMISSION LEVELS

The determination of cost factors resulting from the incorporation of control systems to reduce exhaust emissions requires the examination of several important variables. These cost factors, expressed as dollars expended per ton of pollutant removed ($/ton), depend not only on the particular emission control system (ECS) employed, but also on the "baseline" vehicle emission level (i.e., the characteristic vehicle emissions prior to the incorporation of a given ECS).

This section summarizes the significant results of examinations and analyses of candidate ECS and their characteristic costs, baseline emission level selections, and the effects of ECS selection on gasoline consumption.

3.1 CANDIDATE EMISSION CONTROL SYSTEMS

A technical evaluation of various emission control approaches for MDVs was recently completed for EPA by the Calspan Corporation. The Calspan report (Ref. 3-1) describes in detail the characteristics of eight ECS for possible application to MDVs; seven (ECS No. 2 through ECS No. 8) were selected for cost factor comparisons in the present study. The eighth system (ECS No. 1) was not considered herein because of lack of hydrocarbon (HC) control effectivity.

The components involved and the principal or differentiating feature of each of the seven selected systems are described in Table 3-1. Reference 3-1 contains more comprehensive system descriptions, details, and background information. For convenience of reference between the results of the present study and the Calspan report (Ref. 3-1), the ECS numbers match those given in the Calspan report.

Table 3-1. Candidate Emission Control Systems--Principal Features (Based on Ref. 3-1)

CALSPAN No.	DESCRIPTION	PRINCIPAL FEATURE(1)
2	EI+IC+QHI+AI+EGR	IMPROVED CARBURETION
3	EI+IC+QHI+EGR+AI+OC	OXIDATION CATALYST
4	EI+IC+QHI+EGR+RC+AI/CAI+OC	OXIDATION AND REDUCTION CATALYSTS
5	EI+EFIC+EGR+RC/OC	ELECTRONIC FUEL INJECTION WITH TRICOMPONENT CATALYST
6	EI+IC+QHI+EGR+LTR	LEAN THERMAL REACTOR
7	EI+FC+EGR+AI+RTR	RICH THERMAL REACTOR
8	EI+FIC+IQHI+AI+EGR	ADVANCED LEAN CARBURATION

EI = ELECTRONIC IGNITION
IC = IMPROVED CARBURATION
QHI = FAST WARM-UP INTAKE MANIFOLD
IQHI = ADVANCED INTAKE MANIFOLD
AI = AIR INJECTION
CAI = AIR INJECTION INTO OXIDATION CATALYST
EGR = EXHAUST GAS RECIRCULATION

OC = OXIDATION CATALYST
RC = REDUCTION CATALYST
RC/OC = TRICOMPONENT CATALYST (TRI)
FC = FAST CHOKE
FIC = ADVANCED LEAN CARBURETION
LTR = LEAN THERMAL REACTOR
RTR = RICH THERMAL REACTOR

(1) ALL SYSTEMS HAVE EGR

The ECS characteristics are given in Table 3-2 in terms of resultant exhaust emissions and postulated attendant fuel economy reductions. The values are those from Ref. 3-1, except for the fuel economy reduction value for ECS No. 3. This was stated to be 8 percent in Ref. 3-1, but 5 percent was selected in the present study. Based on previous studies (Ref. 3-2), the fuel economy loss of noncatalytic ECS is primarily a function of the air-fuel ratio employed and the percent exhaust gas recirculation (EGR) flow rate used for oxides of nitrogen (NO_x) control. Since both ECS Nos. 2 and 3 employ EGR for the same amount of NO_x control, both should have similar fuel economy reductions. In this case, it was determined that 5 percent was the more appropriate value to use (Ref. 3-2).

Table 3-2. Candidate Emission Control Systems -- Characteristics (Based on Ref. 3-1)

CALSPAN NO.	DESCRIPTION	EMISSION FACTOR "R"(1)			FUEL ECONOMY REDUCTION, %
		HC	CO	NO_x	
2	EI + IC + QHI + AI + EGR	0.65	0.55	0.60	5
3	EI + IC + QHI + EGR + AI + OC	0.18	0.15	0.60	5(2)
4	EI + IC + QHI + EGR + RC + AI/CAI + OC	0.18	0.15	0.10	12
5	EI + EFIC + EGR + RC/OC	0.18	0.15	0.10	3
6	EI + IC + QHI + EGR + LTR	0.50	0.35	0.375	8
7	EI + FC + EGR + AI + RTR	0.08	0.35	0.17	25
8	EI + FIC + IQHI + AI + EGR	0.40	0.30	0.35	3

(1) $\text{"R"} = \frac{\text{EMISSIONS AFTER CONTROL SYSTEM ADDED}}{\text{BASELINE EMISSIONS BEFORE CONTROL SYSTEM ADDED}}$

(2) DIFFERS FROM 8% USED BY CALSPAN

The emission factor "R" in Table 3-2 is defined by Calspan as:

$$\text{"R"} = \frac{\text{emissions after control system is added}}{\text{baseline emissions before the control system is added}}$$

In the present study, the "R" values as depicted in Table 3-2 were treated as invariant with vehicle age or mileage [i.e., emission degradation or deterioration-with-age factors (DF) were equal to 1 for these "R" values]. Substantive comparative durability test data are not available for all seven systems; when such comparative data are available the emission control cost factors based on these "R" value assumptions (presented in Section 4) can be readily adjusted to account for the appropriate emissions degradation factor (DF). In the case of ECSs containing catalysts, however, it was assumed that catalysts would require replacements at approximately 25,000 mi intervals, and the replacement costs are included in subsequent cost factor calculations. In effect, then, by incorporating converter replacement costs, the catalyst-containing systems were adjusted to account partially for emission degradation in calculating dollars per ton values.

Some of the values shown in Table 3-2 are based on incomplete data and are not conclusive. Data for ECS Nos. 2 and 3 are relatively more documented.

These seven ECSs (Tables 3-1 and 3-2) are used hereafter in computing cost factors for LDVs, MDVs, and some examples of HDVs. All further references to them will be made by ECS number (No. 2 through No. 8).

3.2 BASELINE EMISSION LEVELS

The selection of a meaningful baseline emission level (or levels) is of extreme importance. Pollutant reductions attributed to a given ECS are measured directly from baseline values; therefore, resulting cost factors ($/ton pollutant removed) are directly proportional to the baseline emission level. Because of this relationship, the widest possible data base was examined and analyzed prior to selecting baseline emission levels. Several discrete data sources were available, and each is discussed separately.

3.2.1 Calspan Corporation MDV Correlations

Calspan (Ref. 3-1) performed correlation analyses of the emission data generated in the recently conducted EPA MDV emission characterization program. Regression analyses of seventy-six 1970 to 1973 model year truck emission data samples resulted in the following regression line equations for HC, CO, and NO_x emissions:

$$M_{HC} = (0.526\ I_w + 2.38)\ \text{gm/mi}$$

$$M_{CO} = (7.09\ I_w + 19.8)\ \text{gm/mi}$$

$$M_{NO_x} = (1.02\ I_w + 1.61)\ \text{gm/mi}$$

where the "M" denotes emission mass flow in gm/mi based on Federal LDV driving cycle CVS tests. The I_w of these 76 trucks ranged from 4,500 to 10,000 lb, with an average I_w of approximately 5,740 lb. They consisted of a composite of tuned and untuned vehicle tests. The regression lines are shown in Figures 3-1, 3-2, and 3-3.

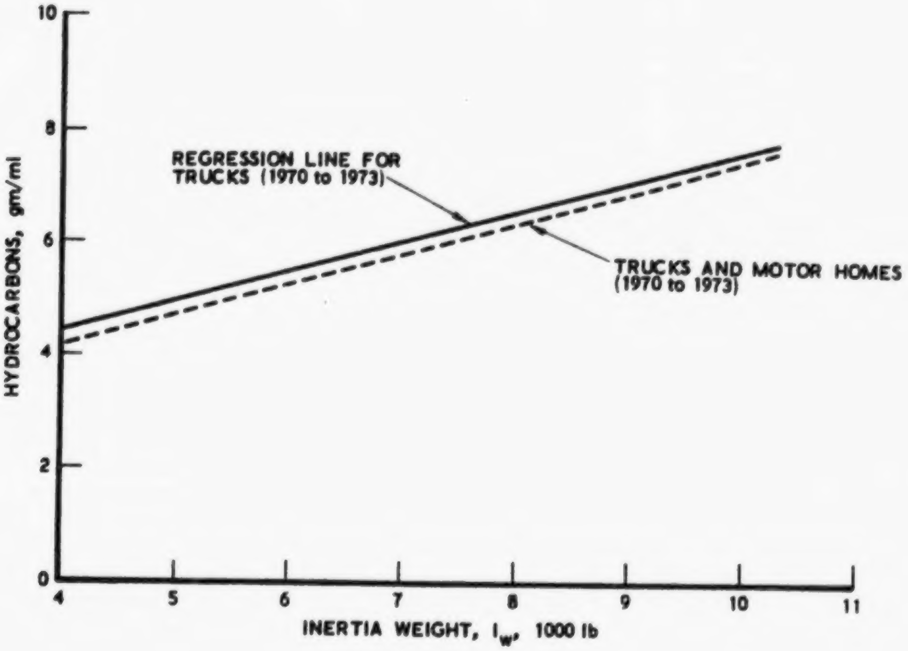

Figure 3-1. Comparison of HC Emissions of Trucks and Motor Homes with Regression Line for Trucks Only (Based on Ref. 3-1)

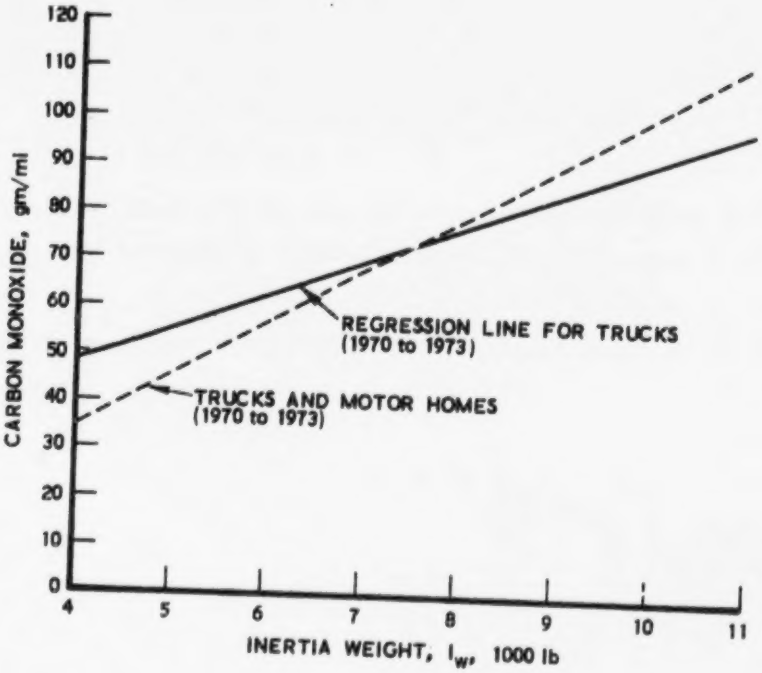

Figure 3-2. Comparison of CO Emissions of Trucks and Motor Homes with Regression Line for Trucks Only (Based on Ref. 3-1)

Test data for motor homes tested in the same program were not originally included in the regression correlations because of apparent data scatter. A later correlation of 135 test data points, including both trucks and motor homes, produced the dotted-line correlations in Figures 3-1, 3-2, and 3-3. Thus, the sensitivity of MDV emission line correlations to excluded or included data samples is clearly evident.

3.1.2 Environmental Protection Agency MDV Correlations by Model Year

Personnel in the Division of Emission Control Technology (DECT), EPA, Ann Arbor, Michigan have further analyzed the data from the MDV emission characterization program (Ref. 3-3). Their analysis results for MDVs as a function of vehicle category and model year are given in Table 3-3. By combining Table 3-3 results with sales data, the composite or sales-weighted MDV emission characteristics as a function of model year are as shown in Table 3-4.

It is estimated that the average I_w for the pickups, vans, and panel truck class was approximately 5650 lb, and for the composite overall MDV class it was approximately 6900 lb. Comparison of the emission values of Tables 3-3 and 3-4 at these I_w values in Figures 3-1 through 3-3 indicates good agreement with the generalized Calspan emission correlations. This is as expected since both analyses were based on data from the same overall MDV emissions characterization program.

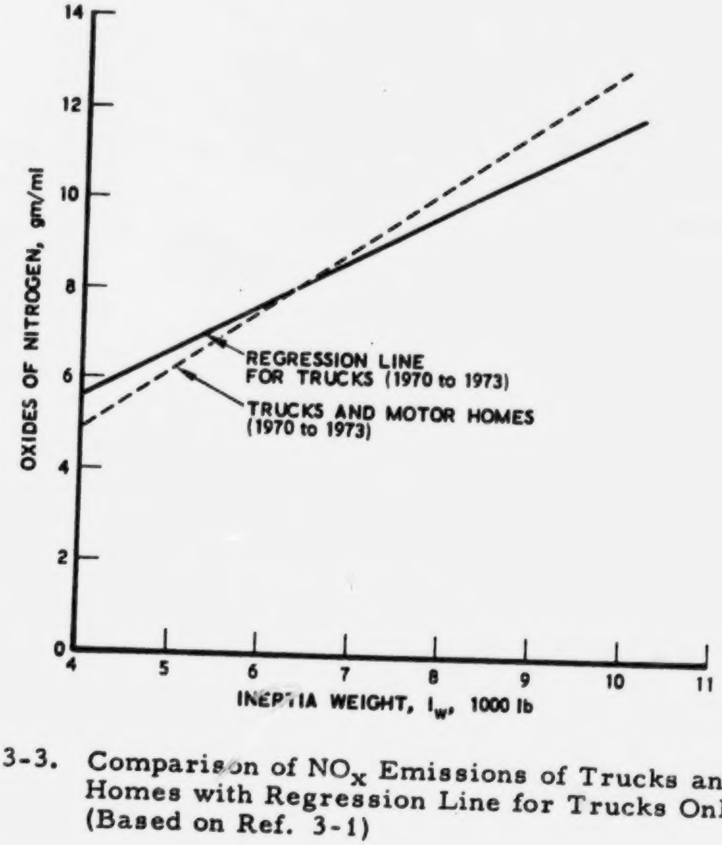

Figure 3-3. Comparison of NO_x Emissions of Trucks and Motor Homes with Regression Line for Trucks Only (Based on Ref. 3-1)

Table 3-3. Emission Values by Category and Model Year (Ref. 3-3)

Model Year	Emissions		
	HC	CO	NO_x
	Pickups, Vans, and Panel Trucks (6,000 to 10,000 GVW)		
1973	4.25	49.22	4.95
1972	4.46	51.56	7.49
1971	5.87	65.52	8.17
1970	5.93	71.78	7.63
1969	7.31	93.59	6.37
1968	10.58	125.35	5.61
1967	11.07	126.15	5.20
1966	12.40	110.95	5.75
1965	10.62	75.51	6.49
	Conventional Motor Homes (6,000 to 14,000 GVW)		
1970 to 1973	8.91	116.27	12.57
Pre-1970		Insufficient Data	
	Chassis and Other MDV (6,000 to 14,000 GVW)		
1970 to 1973	6.78	72.05	8.52
Pre-1970	12.20	113.82	9.43

Table 3-4. Sales-Weighted MDV Emission Values (Ref. 3-3)

Model Year	Emissions		
	HC	CO	NO_x
1973	5.30	62.08	6.57
1972	5.31	61.87	8.21
1971	6.29	70.90	8.60
1970	6.38	75.43	8.23
1969	8.64	99.07	7.20
1968	10.98	122.47	6.56
1967	11.41	122.40	6.49
1966	12.46	110.22	6.30
1965	12.32	97.77	6.11

3.2.3 The 1972 LDV Technology Trends

Another emissions data base examined is that characteristic of 1972 LDV engines. In this regard, Calspan (Ref. 3-1) reported the following values [corrected for the 1975 Federal Test Procedure (FTP)] for a large sample of LDVs.

HC = 1.70 gm/mi
CO = 16.50 gm/mi
NO_x = 4.00 gm/mi

Of interest was the variation in emission rate that would occur if LDV engines with these emission certification characteristics were used in MDVs. It was assumed that such engines probably represent the best available engine technology prior to the incorporation of specific ECS components as exemplified by ECS No. 2 through No. 8 in Tables 3-1 and 3-2. Data from a ten-truck test program conducted by EPA in June through

August 1972 were used to provide this variation of emission rate with I_w characteristic. Of the ten trucks tested (Ref. 3-4), seven to eight were 1972's and from two to three were 1971's. Prior to test, each was checked for exhaust leaks, ignition timing, dwell angle, and idle rpm. If necessary, each was set to manufacturer's specifications in the four areas.

Each of the ten trucks was tested at inertia weights corresponding to 0 percent load (curb weight), 25 percent load, 50 percent load, and 100 percent load (GVW). The resulting emissions test data for each truck are tabulated in Appendix C, and the variations in emission rate with I_w are plotted in Figures 3-4, 3-5, and 3-6 for HC, CO, and NO_x, respectively.

Similar data for two other 1972 model year MDVs (a truck and a motor home) from tests conducted by SwRI were also provided by EPA (Ref. 3-4). These data are given in Appendix C and similarly plotted in Figures 3-4, 3-5, and 3-6 for comparison purposes.

Although as evidenced by the figures, there is considerable variance in absolute emission levels, there are reasonably consistent trends with regard to the rate at which emission (HC, CO, and NO_x) rate changes with increasing I_w, and it is this characteristic that was desired at the outset. The average emission rate of change with the I_w rate of change was determined for the ten trucks tested by EPA, and is denoted on the figures. This average value was based on end points only (0 and 100 percent load points).

A hypothetical "1972 LDV Technology Baseline" variation of emission rate with I_w was constructed which consisted of the 1972 LDV emission certification level up to I_w = 5500 lb plus a variation with I_w above 5500 lb per the Δ emission/ΔI_w slope factor as determined from the EPA ten-truck test series. It is estimated that this characteristic would represent the lowest obtainable emissions with MDV engines incorporating the types of engine modifications (combustion chamber, ignition timing, spark retard, etc.) made to date for LDVs and without the incorporation of ECSs illustrated in Tables 3-1 and 3-2 (ECS No. 2 through No. 8).

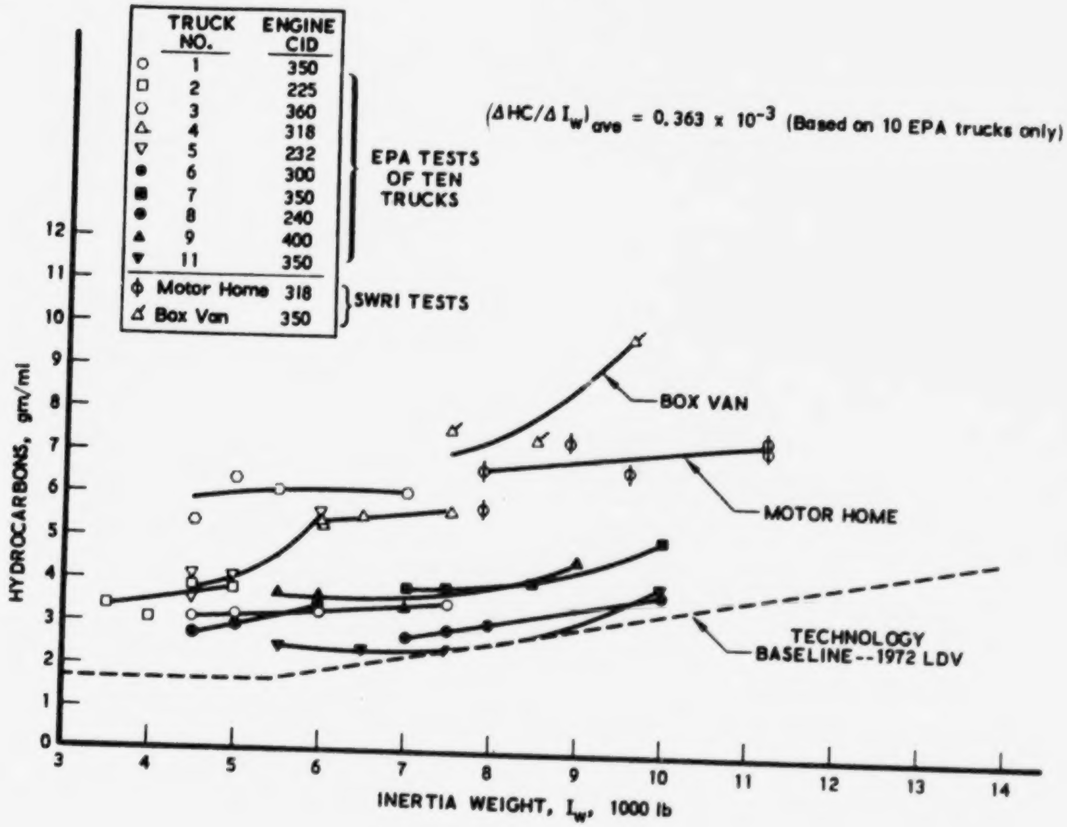

Figure 3-4. Hydrocarbon Emission Rate Variation as a Function of Inertia Test Weight

3.2.4 HDV Emission Factors

Federal HDV engine emission standards have been expressed in terms of concentration [ppm or mole (M) percent] since model year 1969. For 1974, these standards are expressed on a mass basis [i.e., in terms of brake specific emissions (gm/bhp-hr)]. The HDV engines are certified

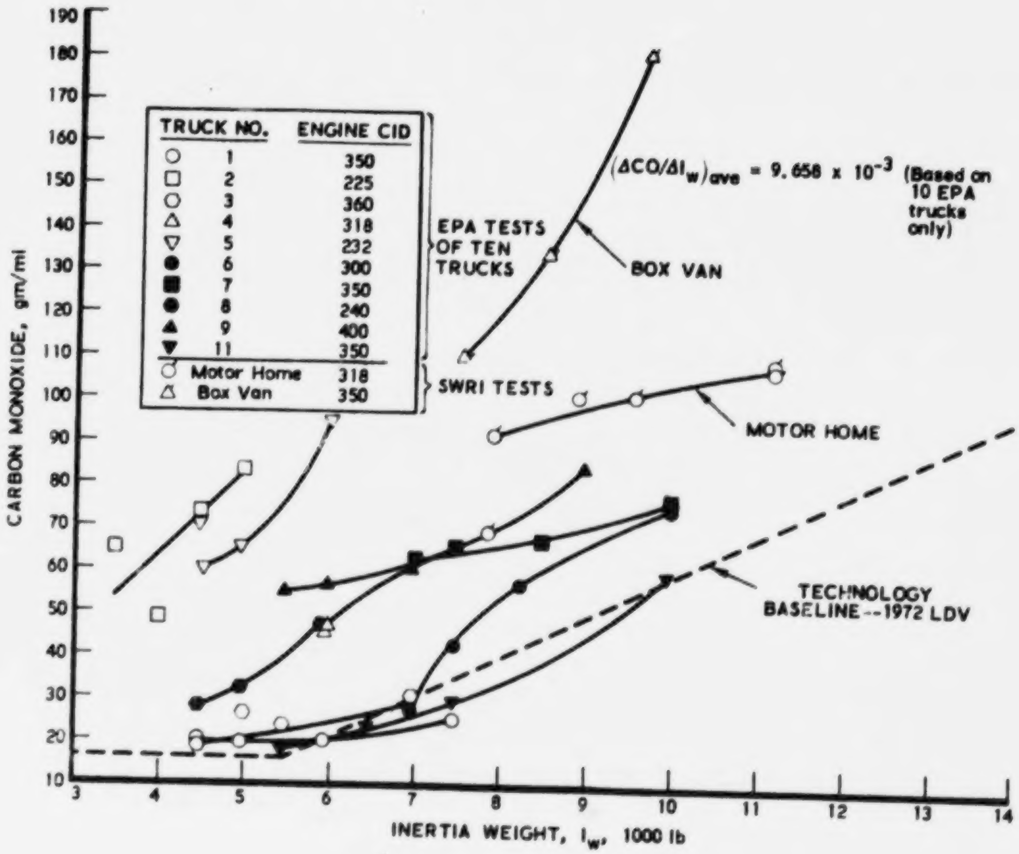

Figure 3-5. Carbon Monoxide Emission Rate Variation as a Function of Inertia Test Weight

to these standards by a prescribed dynamometer test cycle that does not include transient load effects (steady rpm and load conditions only).

Since emission inventories are computed on the basis of gm/mi emission rates, it has been necessary in the past to either actually measure HDV emissions on a mass basis during on-the-road operation, or to attempt to correlate analytically between concentrations (ppm or M percent) or brake specific emissions (gm/bhp-hr) and gm/mi rates. Sigworth (Ref. 3-5) and Bascom and Hass (Ref. 3-6) have used a conversion factor for this purpose that is the bhp-hr/mi expenditure equivalent of the road route or driving cycle over which the vehicle is driven or tested. Thus,

$$\text{gm/mi} = \frac{\text{bhp-hr}}{\text{mi}} \times \frac{\text{gm}}{\text{bhp-hr}} \qquad (3\text{-}1)$$

where

$\frac{\text{gm}}{\text{bhp-hr}}$ = either emissions standards expressed as brake specific emissions (or concentration equivalent) or actual measured brake specific emission rate

$\frac{\text{bhp-hr}}{\text{mi}}$ = CF = conversion factor = $\frac{\overline{\text{HP}}}{\overline{\text{V}}}$

$\overline{\text{HP}}$ = average horsepower expended over driving cycle or route

$\overline{\text{V}}$ = average velocity in mph over driving cycle or route

Using this technique (Equation 3-1), we can determine the gm/mi emission rate by the energy demand of the driving cycle or route ($\frac{\text{bhp-hr}}{\text{mi}}$).

However, both the Ethyl Corporation (Ref. 3-7) and SwRI (Ref. 3-8) have reported difficulty in correlating emission mass measurements from on-the-road operation with mass measurements obtained from the steady-state load conditions of the engine dynamometer test cycle -- FTP. Presumably, this lack of correlation results because the dynamometer test cycle does not include the transient load effects (accelerations, decelerations) experienced in actual driving.

Because of this correlation difficulty, a brief examination and analysis of driving cycle energy requirements and FTP to road load correlations were made. If the correlation anomalies could be resolved, the same predictive techniques could be applied to MDVs, which incorporate HDV engines.

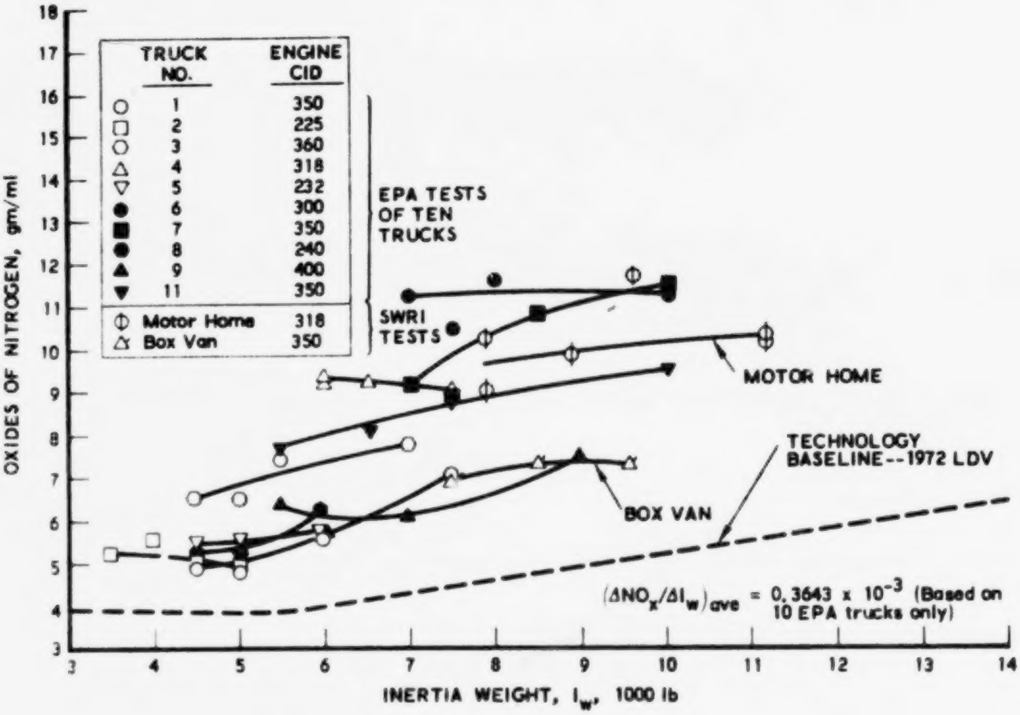

Figure 3-6. Oxides of Nitrogen Emission Rate Variation as a Function of Inertia Test Weight

3.2.4.1 Driving Cycle Energy Correlations

A number of driving cycle energy requirements were determined by computer simulation using the relationship

$$\text{Engine Power Output} = \sum(HP_{ACC} + HP_D + HP_R)$$

where

$$HP_{ACC} = \text{acceleration power} = K \times W \times A \times \frac{V}{375}$$

$$HP_D = \text{drag power} = 0.00227\ C_D \times S \times \frac{V^3}{375}$$

$$HP_R = \text{road friction power} = \frac{V}{375}\left[\frac{W}{2000}\left(10 + \frac{300}{P} + 0.07\frac{V^2}{P}\right)\right]$$

and

W = vehicle weight, lb

A = acceleration, g's

V = velocity, mph

S = vehicle cross-sectional area, sq ft

P = tire pressure, psi

K = rotational inertia constant

C_D = drag coefficient

The driving cycles or road routes simulated included:

a. EPA Urban Dynamometer Driving Schedule (as prescribed in Federal Register) -- also referred to herein as LA-4.

b. Chassis dynamometer cycles developed by the Ethyl Corporation (Ref. 3-7) using road routes in Detroit to simulate Los Angeles driving patterns for three truck weight classes. The DLA routes are referred to herein as:

DLA-1 -- for 6,000 to 10,000-lb GVW class

DLA-2 -- for 10,000 to 19,500-lb GVW class

DLA-3 -- for greater than 19,500-lb GVW class

c. Actual velocity as a function of time profiles for three trucks driven on the San Antonio Road Route (SARR) by SwRI (Ref. 3-9). The SARR tests are referred to herein as:

SARR-1 -- 1970 Ford van, 300-CID I-6, 10,000-lb GVW, 9,740 lb test weight

SARR-2 -- 1969 Dodge, 318-CID V-8, 16,000-lb GVW, 12,800 lb test weight

SARR-3 -- 1972 International Harvester Company (IHC), 304-CID V-8, 19,000-lb GVW, 14,450 lb test weight

d. New York City driving cycle (Ref. 3-10)

Appendix D contains illustrations of velocity as a function of time profiles for items (a) and (d) above, and mode as a function of speed and time tables for item (b) above. Also shown is a layout of the SARR over which the three trucks in (c) above were driven.

The variation of the conversion factor $\overline{HP}/\overline{V}$ as a function of vehicle weight is shown in Figure 3-7 for the Urban Driving Cycle. It also shows the variables and their values that were simulated. In the truck case, the frontal area, drag coefficient, wheel diameter, and rear axle ratio were varied in three discrete steps in accordance with meaningful variations in these parameters as truck GVW increases. Then a single truck "composite" characteristic was selected by connecting the end-points of the 6,000 to 18,000 loaded weight results.

A similar plot of truck-only results for the SARR-3 test truck is given in Figure 3-8. A summary comparison of truck energy requirements for all the cycles examined (on a truck composite basis) is shown in Figure 3-9.

It should be noted that the DLA and SARR lines of Figures 3-8 and 3-9 are based on a single chassis dynamometer cycle (DLA) or a single truck test (SARR). Therefore, these lines depict energy as a function of vehicle weight characteristic trends that apply only to vehicles driven on the same time as a function of velocity profile. A more accurate representation of the overall DLA and SARR composite cycle requirements is illustrated in Figure 3-10, where the discrete individual points on which each characteristic line was based are connected or averaged to arrive at a road-route composite that depicts the variation in cycle characteristics and accompanying cycle energy requirements as the truck weight increases. With increasing truck weight, the rate of increase of $\overline{HP}/\overline{V}$ decreases. In subsequent discussions of DLA and SARR road routes, the composite cycle curves of Figure 3-10 are referred to.

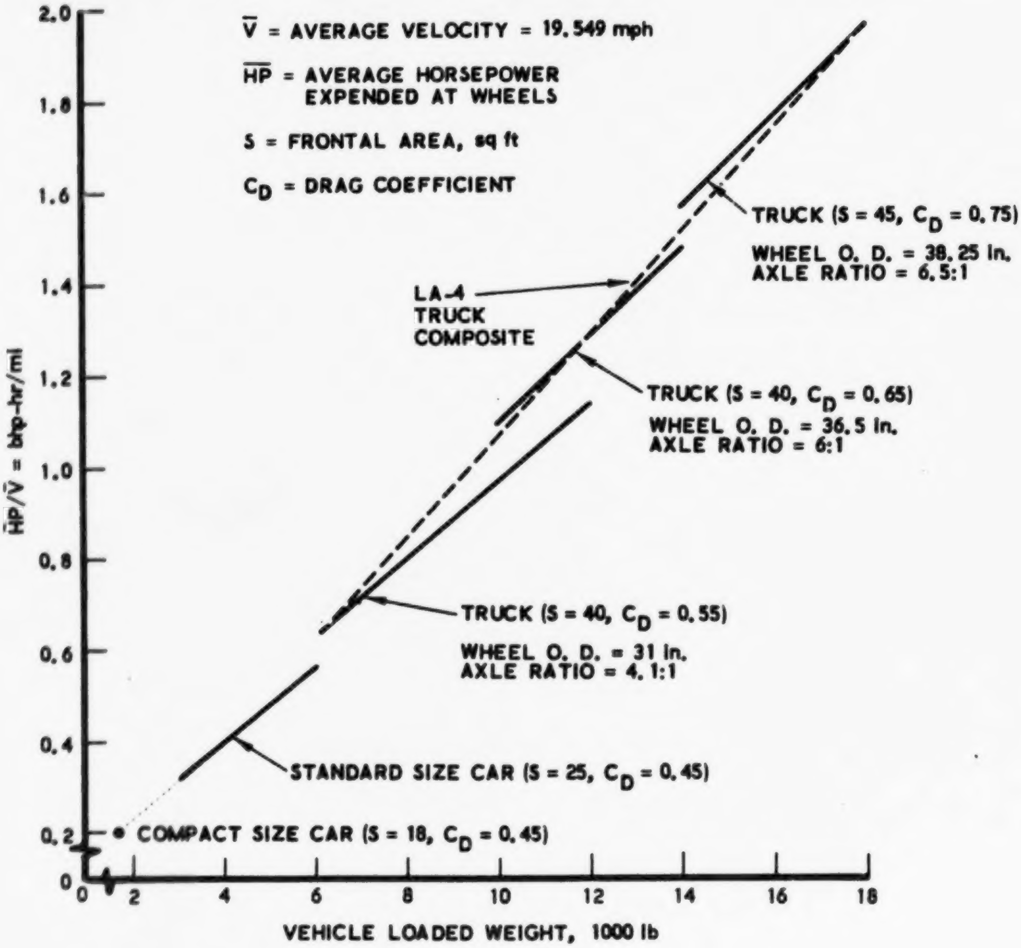

Figure 3-7. The EPA Urban Driving Cycle Power Requirement (LA-4)

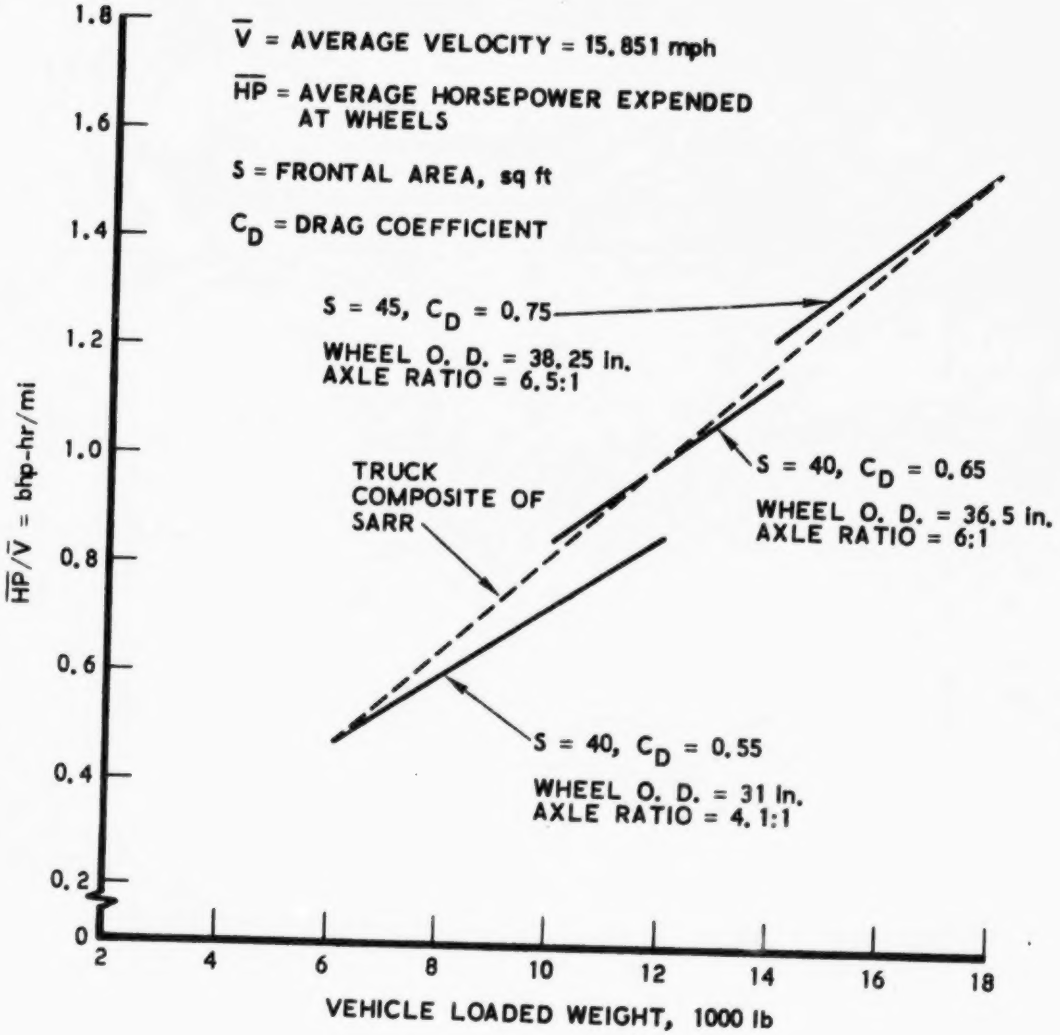

Figure 3-8. San Antonio Route Cycle Power Requirement -- Based on Test of IHC Truck at 19,000-lb GVW and 14,450-lb Test Weight

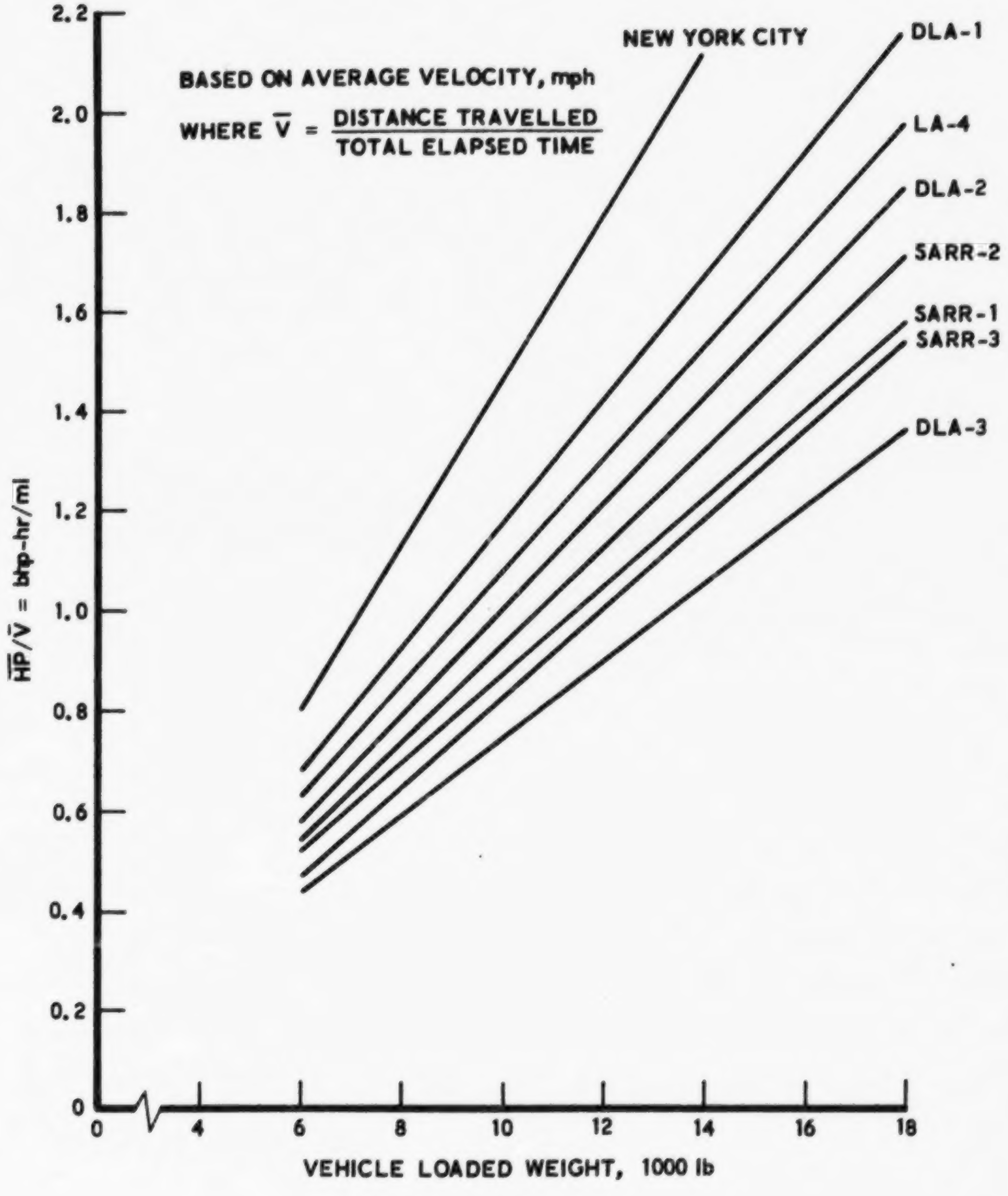

Figure 3-9. Comparison of Truck Energy Requirements for Various Driving Cycles

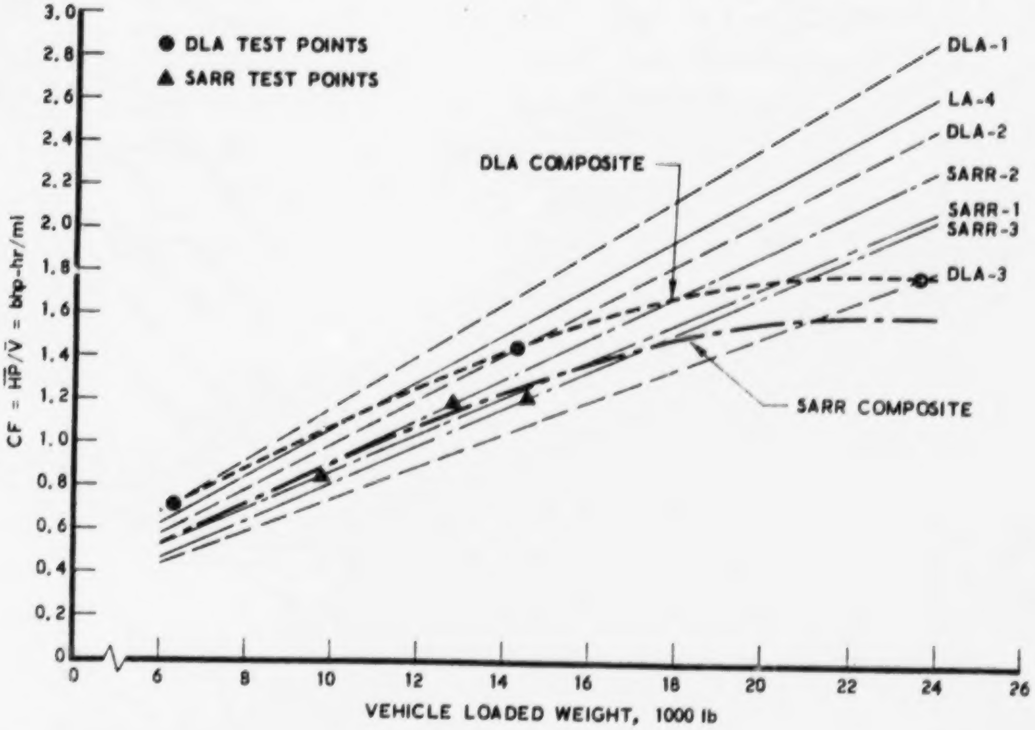

Figure 3-10. The DLA and SARR Cycle Composites

3.2.4.2 The FTP to Road Load Correlations

The SwRI recently compared the emissions from a 25-truck group when operated over the SARR to the emissions from tests of a CVS version of the HDV FTP (Ref. 3-8). They reported the following as averages for the 25-truck group.

Ratio Federal Warm Start FTP/SARR

HC (FIA) = 0.83

CO = 0.69

NO_x = 1.20

These results indicate that, on the average, the FTP produces less HC and CO than road testing, and that the FTP produces more NO_x than road tests. Similar effects were reported by the Ethyl Corporation when correlating road test results with the California heavy-duty engine test cycle (basically the same test as the FTP) (Ref. 3-7).

By segregating the 25-truck fleet into various combinations by weight class, the results in Table 3-5 were obtained (Ref. 3-8). Similar data for the Ethyl Corporation DLA test fleet (Ref. 3-7) are shown in Table 3-6.

Table 3-5. Results of SwRI Comparison of 25-Truck Group

Grouping	Ratio Federal Warm Start FTP/SARR		
	HC	CO	NO_x
MVMA Weight Classes			
6,001 to 10,000-lb GVW	1.21	0.40	1.40
16,001 to 19,500-lb GVW	0.85	0.72	1.11
19,501 to 26,000-lb GVW	0.75	0.61	1.44
26,001 to 33,000-lb GVW	0.73	0.87	0.99
Size and Type			
Small: 10,000-lb GVW vans	1.21	0.40	1.40
Intermediate: 16,000 to 32,000-lb GVW vans and stakes	0.80	0.64	1.24
Large: 24,000 to 32 500-lb GVW truck tractors	0.73	0.80	1.04

The test correlation data in Tables 3-5 and 3-6 are plotted in Figures 3-11, 3-12, and 3-13 for HC, CO, and NO_x, respectively. The solid lines in these figures are a best-estimate fit of the data. All data are plotted at the I_w value corresponding to the average GVW of the class or grouping and the

Table 3-6. Results of Ethyl Corporation Comparison

Weight Class	Ratio California Test Procedure/Road Results		
	HC	CO	NO_x
No. 2 (6,000 to 10,000-lb GVW)	0.38	0.59	1.65
No. 3 (10,000 to 19,500-lb GVW)	0.37	0.48	1.18
No. 4 (greater than 19,500-lb GVW)	0.50	0.68	0.96

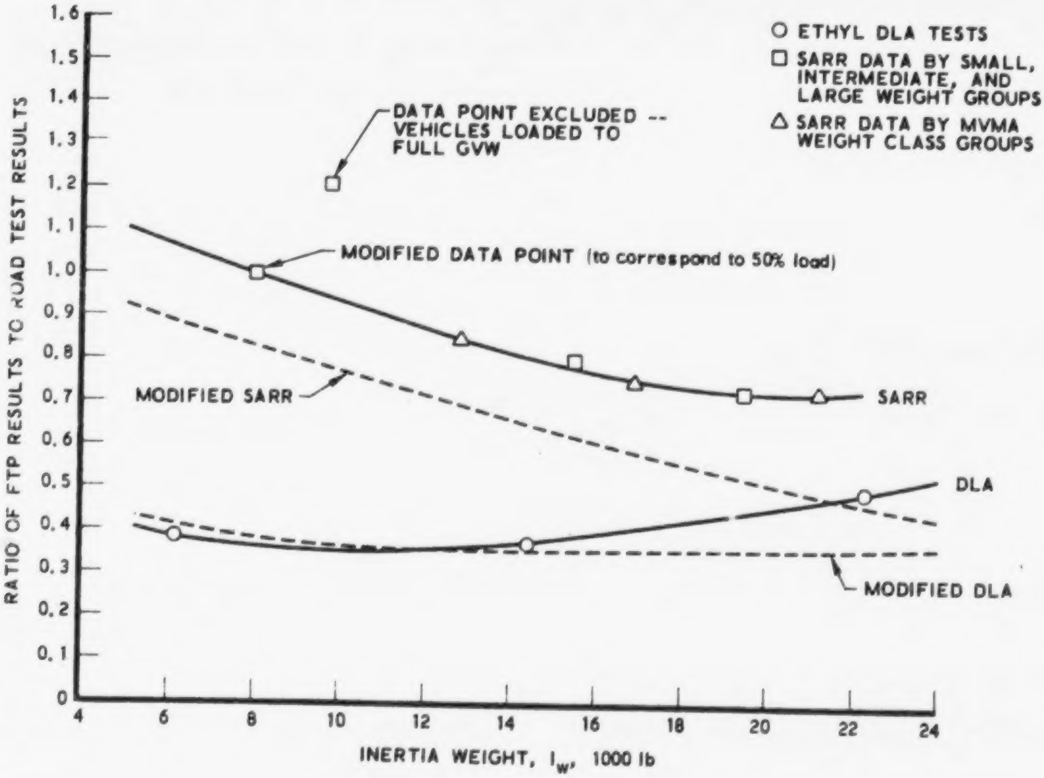

Figure 3-11. Federal Test Procedure to Road Load Hydrocarbon Correlation

I_w as a function of GVW correlation of Figure 2-2. Attention is drawn to the SARR data point at 9740 lb I_w in all three figures. These data are based on 10,000-lb GVW vans that were tested at essentially full GVW due to the weight of the trailer instrument package needed for measuring and recording purposes. All other data (both SARR and DLA) are based on a payload of 50 percent of capacity. However, a similar Ford 10,000-lb GVW van with a 300-CID engine and automatic transmission had been tested at EPA under both 50 and 100 percent load conditions (vehicle No. 6 in Appendix C-1). Therefore, the emission data for this SARR vehicle group were adjusted by the ratio of the 50 to 100 percent emission values of the EPA test, and plotted

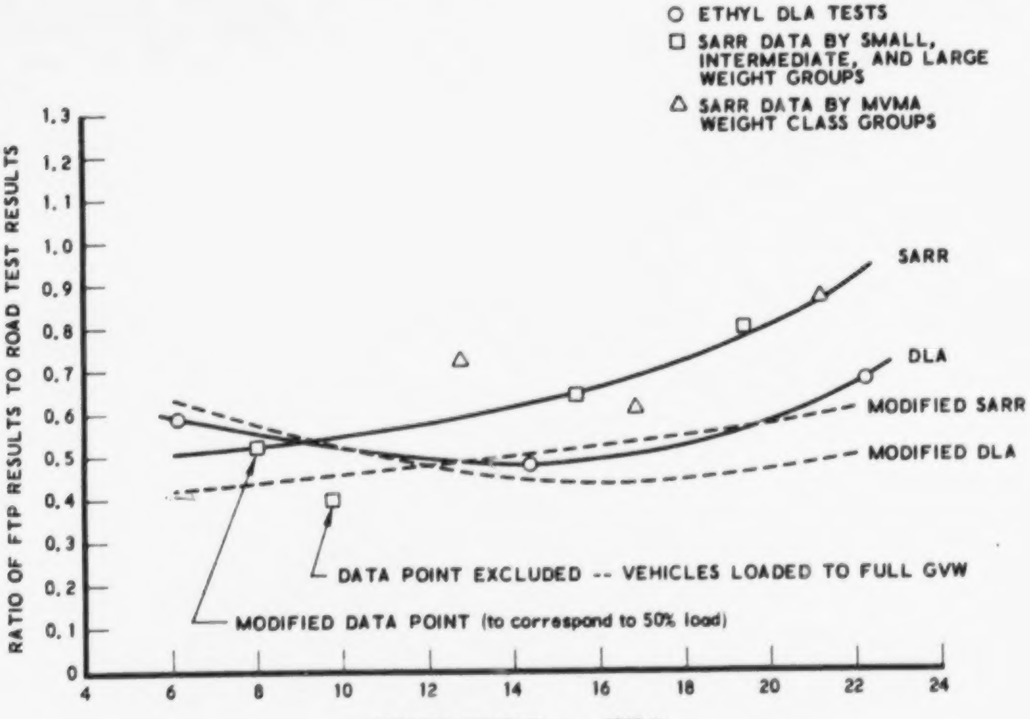

Figure 3-12. Federal Test Procedure to Road Load Carbon Monoxide Correlation

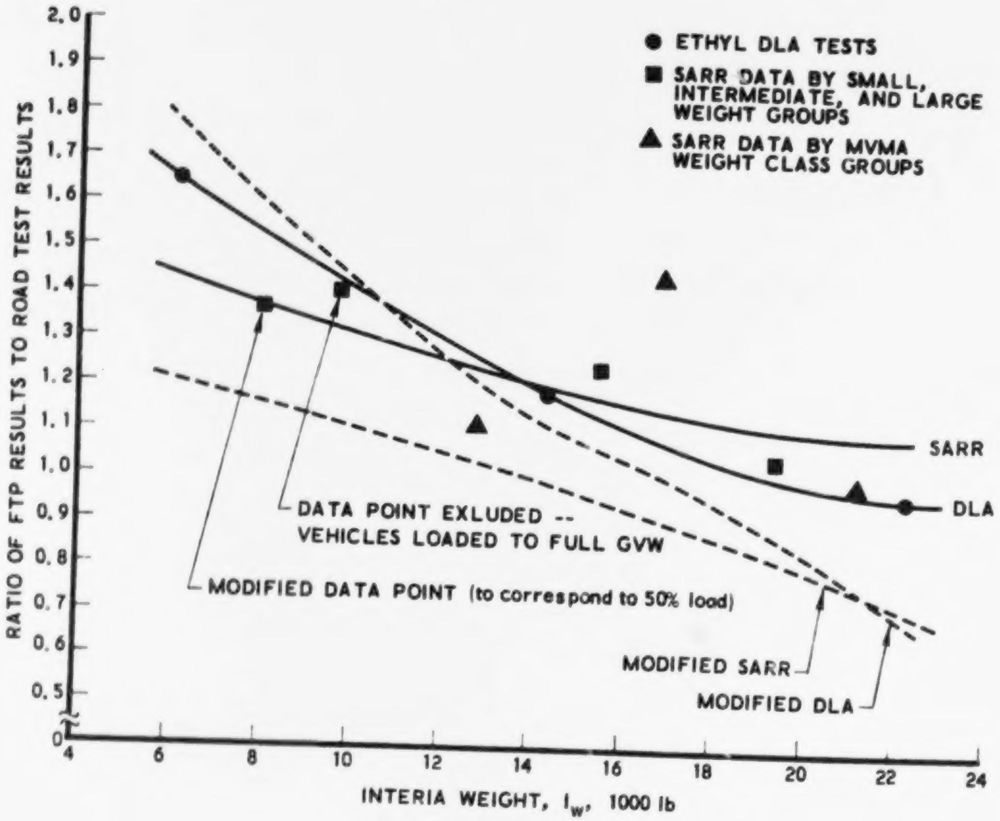

Figure 3-13. Federal Test Procedure to Road Load Oxides of Nitrogen Correlation

at the 50 percent load I_w value for a 10,000-lb GVW vehicle. These data are denoted at the "modified" data point in the three figures. The resulting best-fit curves (solid lines) are in fair agreement for CO and NO_x, but are considerably at variance for HC.

Since the composite cycle energy requirements of the SARR and DLA routes are considerably different (see Figure 3-10), the emissions correlations of Figures 3-11, 3-12, and 3-13 were normalized with the Urban Driving Cycle (LA-4) used as the basis for normalization. Figure 3-14

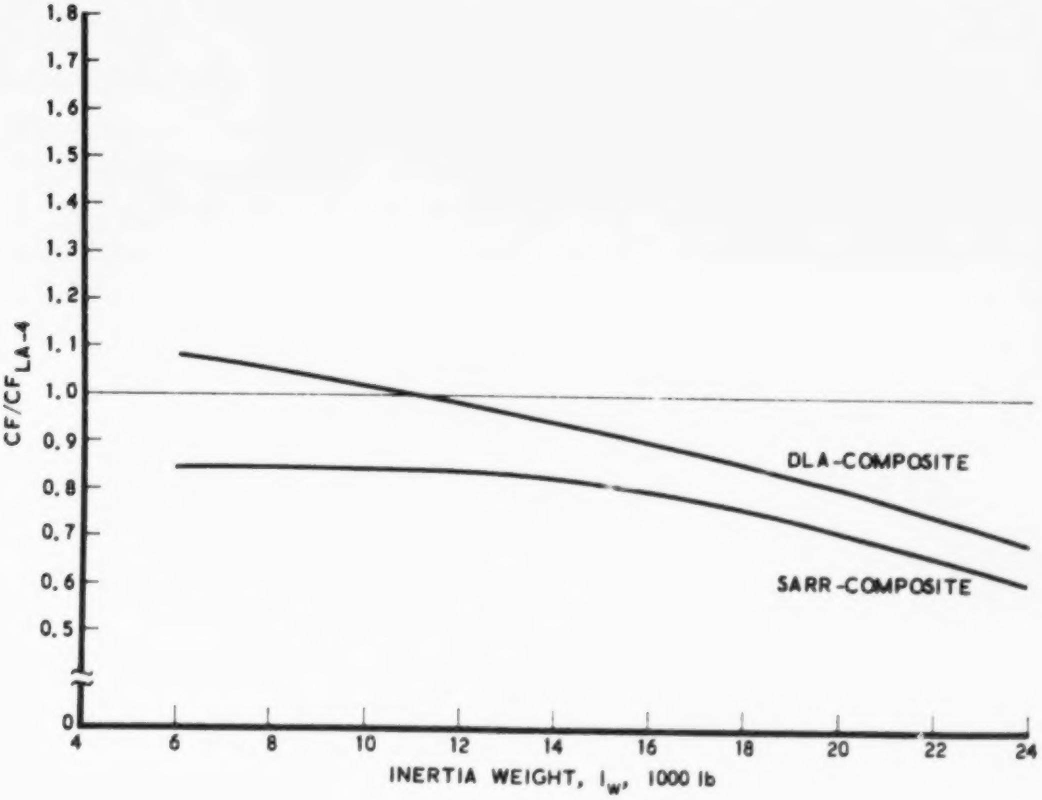

Figure 3-14. The DLA and SARR Correction Factors Relative to EPA Driving Cycle Energy Requirements

illustrates the correction factor ratio of the DLA and SARR routes as compared with the LA-4 route. The correlation lines of Figures 3-11, 3-12, and 3-13 were adjusted by these ratios, with the results shown as dotted lines in the figures and labeled "modified SARR" and "modified DLA."

Again, the normalized SARR and DLA values are at variance. The HC values (Figure 3-11) seem to be converging at I_w values above 24,000 lb. The CO values (Figure 3-12) converge in the 12,000-lb I_w range, but diverge above and below this value. The NO_x values (Figure 3-13) converge at the higher I_w values, as in the case of HC.

It is difficult to determine the reason for the different characteristics exhibited by the DLA and SARR data. The DLA trucks were older and their engines not subject to emission control; whereas the SARR trucks were newer and subject to the first level of heavy-duty engine emission control. It is possible that engine modifications made to comply with emissions standards (combustion chamber, ignition timing, spark retard, etc.) could account for some of these variances.

3.2.4.3 Overall Emissions Correlations

The foregoing FTP to road emissions correlations suggest that the predictive technique of Eq. (3-1) should be modified to account for this demonstrated effect. Then brake specific emissions could be converted to gm/mi on the FDC as follows.

$$\text{gm/mi} = \text{gm/bhp-hr} \times \frac{\text{bhp-hr}}{\text{mi}} \times \frac{\text{Road Load}}{\text{9-mode FTP}}\ \text{Ratio} \qquad (3\text{-}2)$$

where

$\frac{\text{Road Load}}{\text{9-mode FTP}}$ Ratio = "modified SARR" curves in Figures 3-11, 3-12, and 3-13

$\frac{\text{bhp-hr}}{\text{mi}}$ = values for LA-4 route in Figure 3-10

gm/bhp-hr = assigned values to be converted; e.g., Federal or California standards, certification test values, etc.

Table 3-7 summarizes the applicable HDV emissions standard for 1969 through 1975 for both California and the rest of the nation. As indicated by the footnote on the table, the change in test procedures in 1973 in California to brake specific emission measurements did not, by

Table 3-7. Heavy-Duty Vehicle Standards -- >6000-lb GVW

EMISSION	TEST PROCEDURES (Engine Dynamometer)						
	CONCENTRATION (ppm or M%)				MASS (gm/bhp-hr)		
	YEAR						
	1969 CALIF./FED.	1970 TO 71 CALIF./FED.	1972 CALIF./FED.	1973 FED.	1973 TO 74 CALIF.	1974 FED.	1975 CALIF.
HC	275(1) NR	275	180(2) 275	275	16(3)		5(4)
NO_x	NR	NR	NR	NR			
CO	1.5(5) NR	1.5	1.0(6) 1.5	1.5	40		25

(1) EQUIVALENT TO 7.65 gm/bhp-hr

(2) EQUIVALENT TO 5.0 gm/bhp-hr

(3) PER CALIF. AIR RESOURCES BOARD, NO INTENTION TO REDUCE HC LEVEL BUT TO BRING NO_x UNDER CONTROL; PRESUMED 5/11 SPLIT (Ref. 3-11)

(4) PER (3), WOULD BE 1.56/3.44 SPLIT

(5) EQUIVALENT TO 60.0 gm/bhp-hr

(6) EQUIVALENT TO 40.0 gm/bhp-hr

design or intention, include a reduction in allowable HC. The intent was to keep the HC level at 5.0 gm/bhp-hr and bring NO_x under control for the first time at approximately 11.0 gm/bhp-hr. However, the two species (HC and NO_x) were combined for flexibility purposes. In the following correlations, the ratio of HC to NO_x of 5 to 11 is maintained for years 1973 to 1975, to display the two species separately.

Figures 3-15, 3-16, and 3-17 give the results of using Eq. (3-2) to predict the variation of emission rate with I_w on the FDC for HC, CO, and NO_x, respectively. Both Federal and California HDV emission standards were used as inputs, as well as 1973 HDV certification test averages (Ref. 3-12).

For comparison purposes, the 1973 model year EPA test values for pickups, vans, and panel trucks and the overall sales-weighted

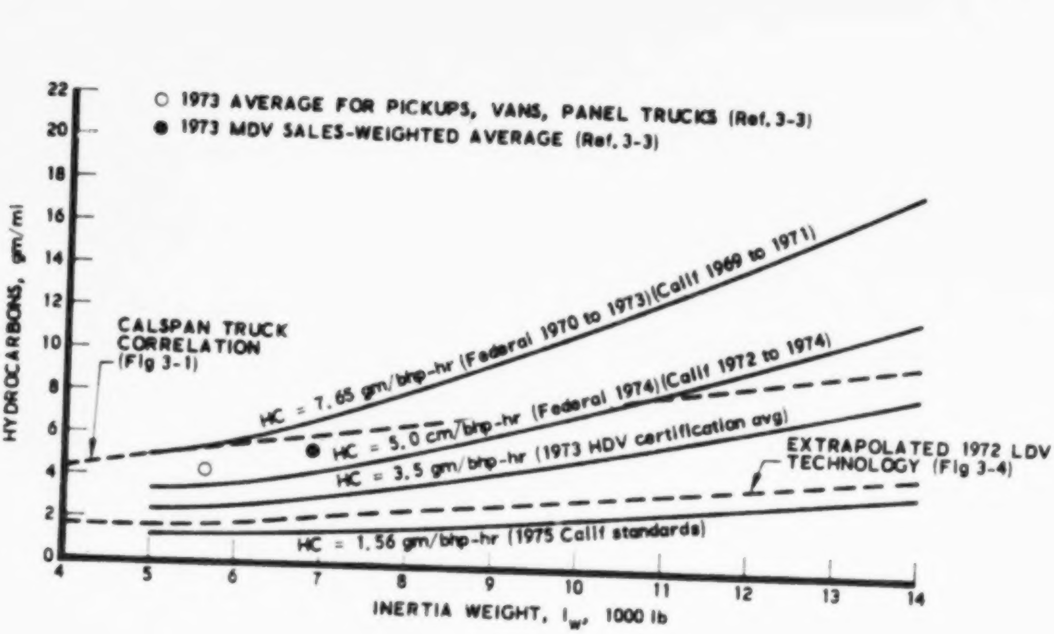

Figure 3-15. Hydrocarbon Emission Variations with Inertia Test Weight -- Federal Driving Cycle (LA-4)

1973 MDV values are shown. In addition, the Calspan truck correlations (Figures 3-1, 3-2, and 3-3) and the extrapolated 1972 LDV technology correlations (Figures 3-4, 3-5, and 3-6) are similarly displayed.

In the case of HC (Figure 3-15), the predicted characteristic has a steeper slope than the Calspan truck correlation. The EPA 1973 truck test averages shown agree reasonably well in terms of slope, but are higher in absolute value than that predicted by 1973 certification test averages for HDV engines.

For CO and NO_x (Figures 3-16 and 3-17, respectively, the predicted characteristics have a slope very similar to the Calspan truck correlation line. The EPA 1973 truck test averages shown again agree reasonably well with the slope, but are higher in absolute value than that predicted by 1973 certification test averages for HDV engines.

In all cases, there is a lack of data to confirm the predicted emission levels at I_w values above approximately 7000 lb. Therefore, the overall validity of this promising emission prediction technique cannot be firmly established until data at higher I_w values are available and until the variance between road measured emission values and HDV engine certification test levels can be satisfactorily accounted for.

3.2.5 Final Emission Baseline Selections

Because of the uncertainties in the foregoing emission prediction technique, the truck emission correlation developed by Calspan from the EPA MDV emissions characterization program was used as representative of the MDV class prior to the addition of specific ECSs. It is

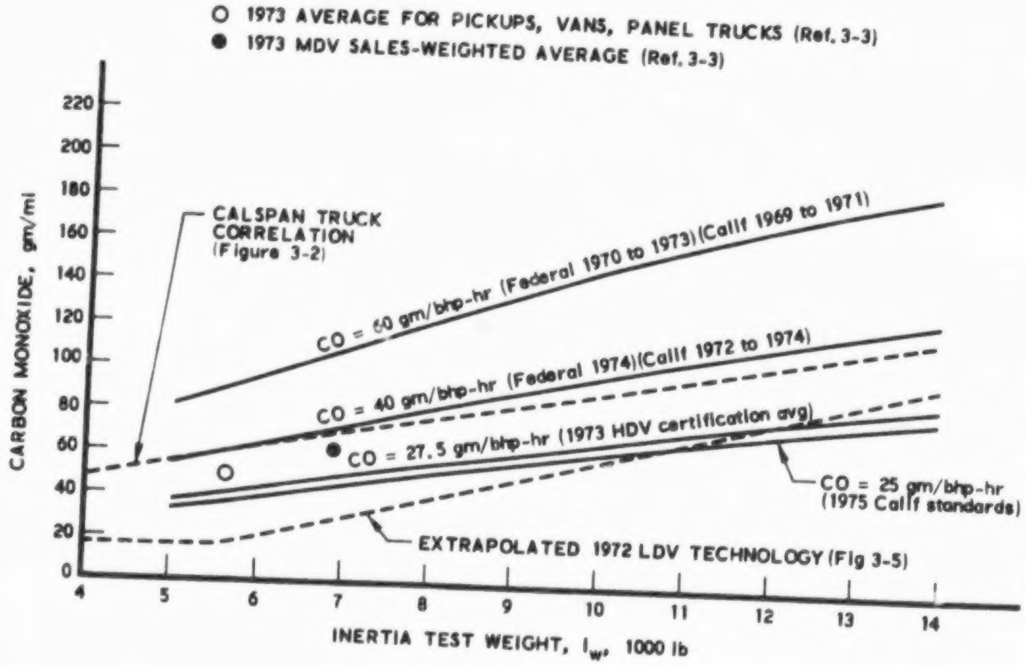

Figure 3-16. Carbon Monoxide Emission Variations with Inertia Test Weight -- Federal Driving Cycle (LA-4)

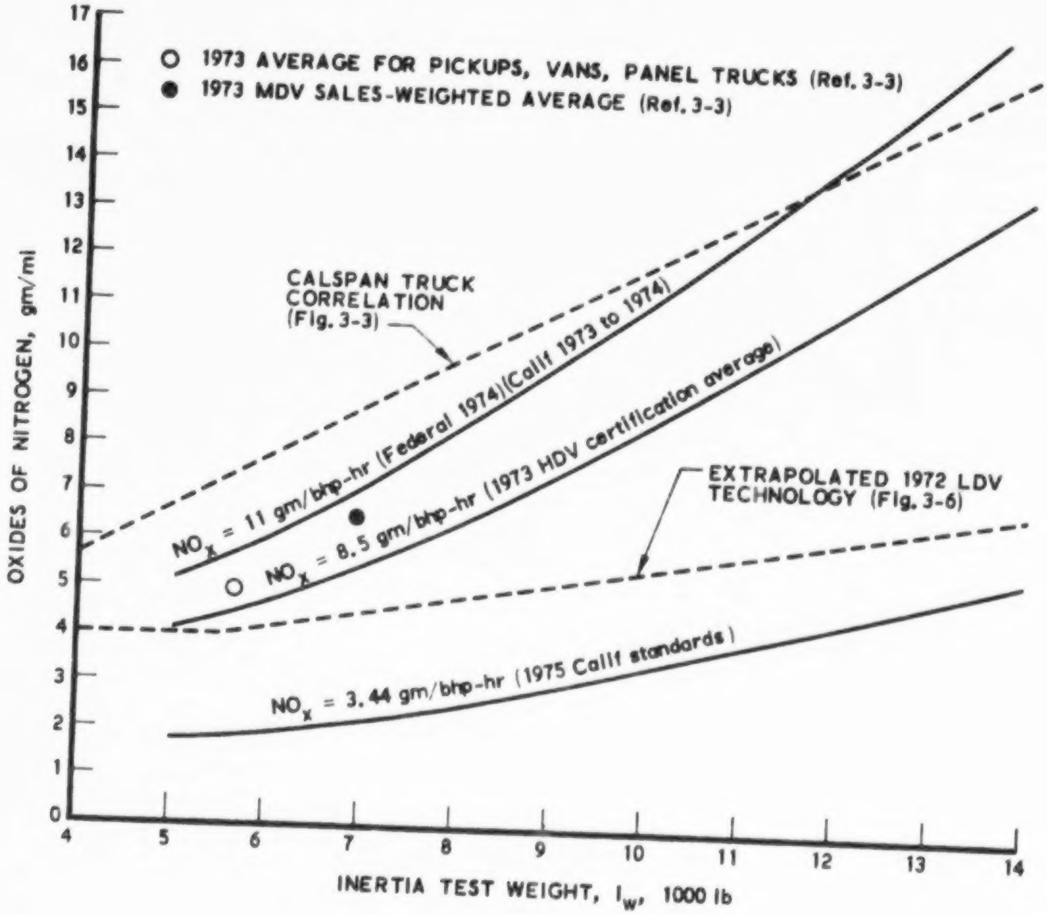

Figure 3-17. Oxides of Nitrogen Variations with Inertia Test Weight -- Federal Driving Cycle (LA-4)

treated herein as an "earlier" technology baseline inasmuch as HDV engines will be modified to meet the more stringent requirements of the California 1975 HDV standards.

Since, as mentioned earlier, cost factors ($/ton of pollutant removed) are directly proportional to baseline emission assumptions, a second emission level baseline was also used -- the extrapolated 1972 LDV technology emission characteristics. It is considered that these two baselines encompass the spectrum of MDV emission characteristics that can be reasonably expected of MDVs that do not have the specific ECSs of Table 3-1 applied to them. Hence, by computing cost factors based on these two baselines, the range of reasonably anticipated cost factors will be obtained.

The two selected emissions baselines are summarized in Figures 3-18, 3-19, and 3-20. Also shown, for comparison purposes, are characteristic 1968 LDV emission values, which can be considered representative of "earlier" technology LDVs (from Kircher and Armstrong, Ref. 3-13). Because of the rather steep slope of the extrapolated 1972 LDV technology characteristic for CO (Figure 3-19), an alternate baseline was arbitrarily selected to test the line slope sensitivity.

3. 3 EMISSION CONTROL SYSTEM COSTS

In developing the ECS costs reported herein, the initial hardware costs and maintenance cost assumptions as reported by Calspan (Ref. 3-1) for ECS No. 2 through No. 8 were used. These ECSs and their costs were applied to both the LDV and MDV cases of Table 2-1.

Since cost factor determination is based on emission reduction, it was necessary to compute both costs and emission reductions over the complete vehicle lifetime to amortize the effects of initial hardware costs. The analysis and assumptions relative to average vehicle lifetimes are presented below, followed by a summary of resultant ECS costs.

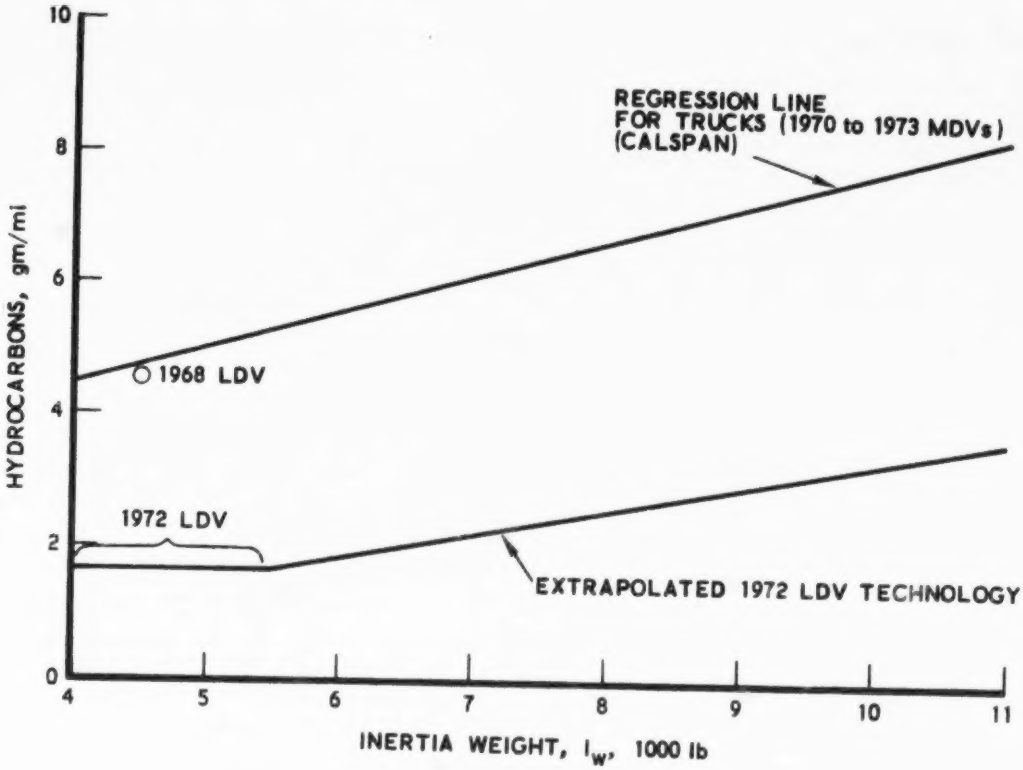

Figure 3-18. Hydrocarbon Emission Baselines Used for Cost Comparisons

3.1 Vehicle Average Lifetime

Reference 3-2 has reported the average lifetime of passenger cars as 8.4 years and 85,000 mi. These values were used herein for the LDV case. For the MDV, or truck case, similar data were not available. Therefore, an analysis of average truck lifetime values was performed, as indicated in Figure 3-21. The R. L. Polk Company truck registration data referred to in the figure are those presented in various issues of Ref. 3-14.

The variation of annual truck mileage with model year used was that given by Kircher and Armstrong in Table 16 of Ref. 3-13. The

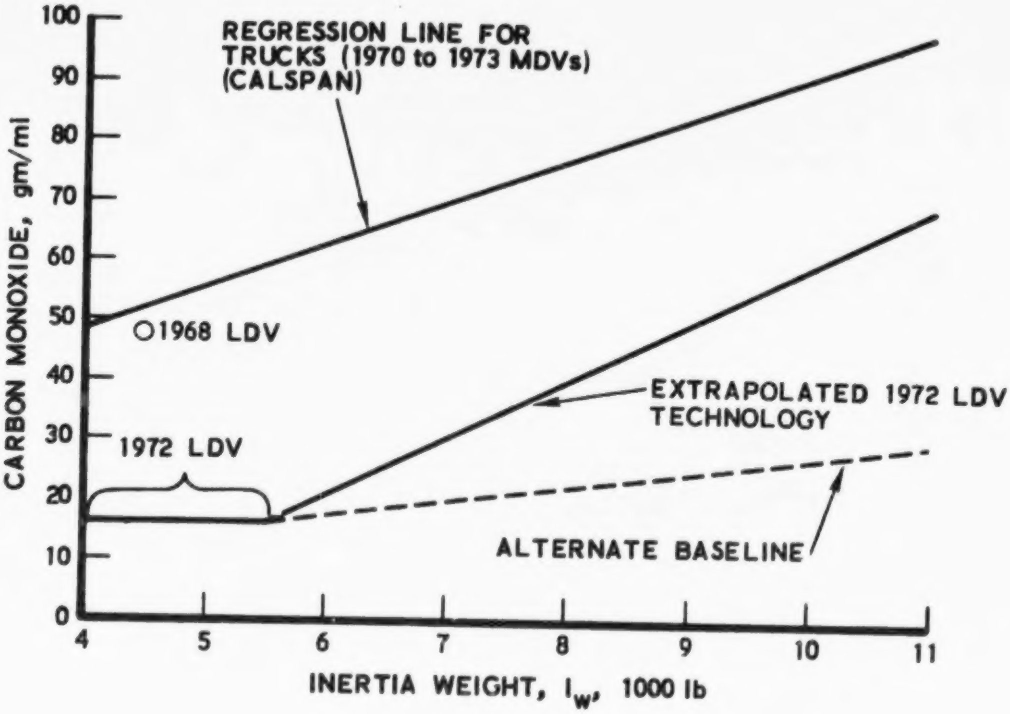

Figure 3-19. Carbon Monoxide Emission Baselines Used for Cost Comparisons

average lifetime truck mileage on this basis for all trucks was computed to be approximately 130,000 mi. Since MDVs are single-unit trucks, the ratio of miles traveled by single-unit trucks compared with total trucks (9,871/11,565 as reported in Ref. 3-14 for the year 1969) was used to arrive at the 110,000 mi average shown in Figure 3-21.

There was no similar basis for differentiating between MDVs and all trucks on the basis of average age; therefore, the truck average age of 12.6 years was used for both MDVs and HDVs in the present cost analysis.

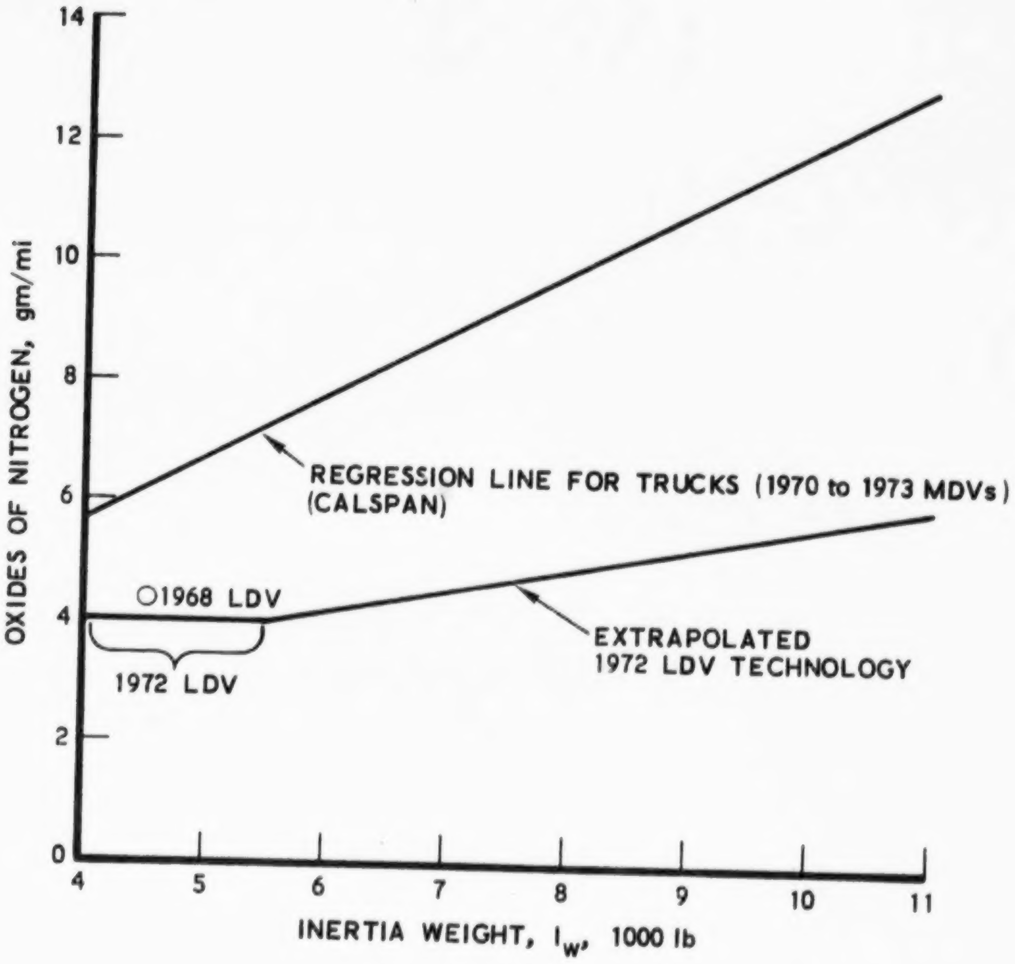

Figure 3-20. Oxides of Nitrogen Emission Baselines Used for Cost Comparisons

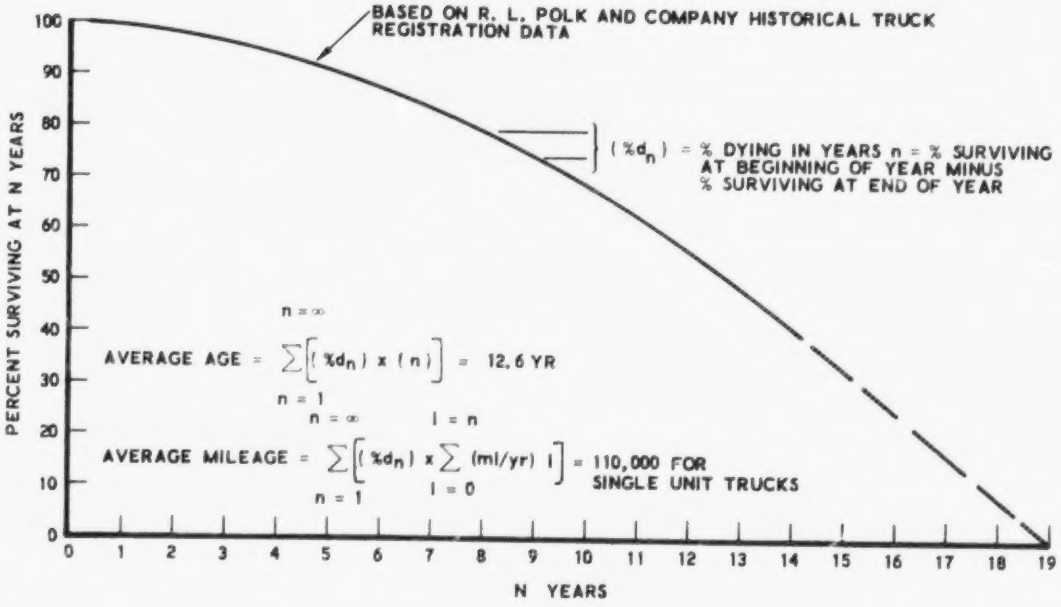

Figure 3-21. Average Truck Lifetime -- Years and Mileage

3.3.2 Cost Summaries

A summary of ECS initial costs is given in Table 3-8[1]. These costs apply to both the LDV and MDV cases examined, since all LDVs and MDVs use the same 350-CID engine. To determine cost factors ($/ton pollutant removed) for each exhaust species (HC, CO, and NO_x), it was necessary to apportion costs on this basis. The following assumptions were made in this regard.

a. One-third of the costs of electronic ignition, testing or inspection,[2] and tricomponent catalysts was allocated to each constituent (HC, CO, and NO_x).

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[1] Certification costs are not included. It was assumed that they would be similar to current LDV and HDV engine certification costs.

[2] Testing or inspection may or may not be required; if required, costs may be different from those assumed.

Table 3-8. Emission Control System Initial Cost Summary -- LDV or MDV; 350-CID Engine

COMPONENTS	CALSPAN No.						
	2	3	4	5	6	7	8
ELECTRONIC IGNITION (EI)(1)	20	20	20	20	20	20	20
FAST CHOKE (FC)						5	
QUICK HEAT INTAKE (QHI)	5	5	5		5		5
IMPROVED CARB. (IC)	10	10	10		10		
ADVANCED CARB. (AC)							30
ELECTRONIC FUEL INJ. (EFI)				100			
EXHAUST GAS RECIRC - (EGR)(2)	30	30	30	30	30	30	30
THERMAL REACTOR (LTR/RTR)					59	59	
AIR INJECTION (AI)	38	39	39			38	38
OXIDIZING CATALYST (OC)		69	70				
REDUCING CATALYST (RC)			90(2)				
TRICOMPONENT CATALYST (TRI)				67(1)			
CATALYST BYPASS		10	10	10			
EVAPORATIVE CONTROL SYSTEM (EVAP. CS)	14	14	14	14	14	14	14
TESTING OR INSPECTION(1)(3)	7	7	7	7	7	7	7
TOTAL	124	204	295	248	145	173	144
HC/CO RELATED	85	165	166	187	106	134	105
NO_x RELATED	39	39	129	61	39	39	39

(1) 1/3 COST ALLOCATED TO EACH CONSTITUENT (HC, CO, NO_x)

(2) COST ALLOCATED TO NO_x CONTROL ONLY

(3) MAY OR MAY NOT BE REQUIRED; COSTS MAY BE DIFFERENT THAN THOSE ASSUMED

b. The EGR and reducing catalyst costs were allocated to NO_x control only.

c. All other costs were allocated to HC/CO control and were divided equally between HC and CO.

Maintenance costs are summarized in Table 3-9 for the LDV and in Table 3-10 for the MDV. The maintenance assumptions are the same for both cases and are based on the Calspan report (Ref. 3-1). The resulting LDV and MDV cost differences are related to the different average lifetime values, as shown. Again, the assumptions made in apportioning costs to HC, CO, and NO_x were as follows.

a. One-third of the costs or savings of electronic ignition, tricomponent catalysts, and inspections was allocated to each constituent (HC, CO, and NO_x).

b. The EGR and reducing catalyst costs were allocated to NO_x control only.

c. All other costs were allocated to HC/CO control and were divided equally between HC and CO.

The maintenance costs for catalytic converter replacements were based on the replacement intervals stated in the tables.

The lifetime fuel costs for the LDV and MDV cases are summarized in Table 3-11. The fuel economy values shown conform to Figure 2-3, and the fuel economy penalties attributed to emission control are based on Table 3-2. The basic fuel cost used, 38¢/gal, is considered a nominal value.

Table 3-9. Emission Control System Maintenance Costs -- LDV; 350-CID Engine (8.4 years and 85,000 mi)

MAINTENANCE ASSUMPTIONS, \$/mi	COMPONENT	CALSPAN No.						
		2	3	4	5	6	7	8
-60/50,000 (1)	EI	-102	-102	-102	-102	-102	-102	-102
NONE REQUIRED	FC							
NONE REQUIRED	QHI							
15/50,000	IC	26	26	26		26		
45/50,000	AC							77
28/50,000	EFI				48			
4/10,000 (2)	EGR	34	34	34	34	34	34	34
NONE REQUIRED	LTR/RTR							
10/25,000	AI	34	34	34			34	34
107/25,000 (3)	OC		214	214				
143/25,000 (3)	RC			286 (2)				
110/25,000 (3)	TRI				220 (1)			
5/10,000	BYPASS		42	42	42			
12.50/25,000	EVAP. CS	42	42	42	42	42	42	42
3/YEAR (1)	INSPECTION	25	25	25	25	25	25	25
TOTAL		59	315	601	309	25	33	110
HC/CO RELATED		51	307	307	228	17	25	102
NO_x RELATED		8	8	294	81	8	8	8

(1) 1/3 OF COST OR SAVINGS ALLOCATED TO EACH CONSTITUENT (HC, CO, NO_x)

(2) COST ALLOCATED TO NO_x CONTROL ONLY

(3) CONVERTERS CHANGED AT 25,000 AND 50,000 mi ONLY

Table 3-10. Emission Control System Maintenance Costs -- MDV, 350-CID Engine (12.6 years and 110,000 mi)

MAINTENANCE ASSUMPTIONS, $/mi	COMPONENT	CALSPAN No. 2	3	4	5	6	7	8
-60/50,000 (1)	EI	-132	-132	-132	-132	-132	-132	-132
NONE REQUIRED	FC							
NONE REQUIRED	QHI							
15/50,000	IC	33	33	33		33		
45/50,000	AC							99
28/50,000	EFI				62			
4/10,000 (2)	EGR	44	44	44	44	44	44	44
NONE REQUIRED	LTR/RTR							
10/25,000	AI	44	44	44			44	44
107/25,000 (3)	OC		321	321				
143/25,000 (3)	RC			429 (2)				
110/25,000 (3)	TRI				330 (1)			
5/10,000	BYPASS		55	55	55			
12.50/25,000	EVAP. CS	55	55	55	55	55	55	55
3/YEAR (1)	INSPECTION	38	38	38	38	38	38	38
TOTAL		82	458	887	452	38	49	148
HC/CO RELATED		69	445	445	329	25	36	135
NO_x RELATED		13	13	442	123	13	13	13

(1) 1/3 COST OR SAVINGS ALLOCATED TO EACH CONSTITUENT (HC, CO, NO_x)

(2) COST ALLOCATED TO NO_x CONTROL ONLY

(3) CONVERTERS CHANGED AT 25,000; 50,000; AND 75,000 mi ONLY

Table 3-11. Fuel Cost Summary -- Over Vehicle Lifetime (85,000 mi for LDV; 110,000 mi for MDV)

PARAMETER	LDV	MDV NO. 1 TRUCK "A" (I_w=6,000)	NO. 2 TRUCK "B" (I_w=9,000)	NO. 3 MOTOR HOME (I_w=11,000)	NO. 4 TRUCK "C" (I_w=14,000)
FUEL ECONOMY, mpg	12.0	10.0	7.25	6.20	5.40
GALLONS USED	7090	11,000	15,170	17,720	20,350
FUEL COST @ 38¢/gal	$2700	$4185	$5760	$6740	$7740
FUEL PENALTY COST, $					
ECS NO. 2 (5%)	135	209	288	337	387
ECS NO. 3 (5%)	135	209	288	337	387
ECS NO. 4 (12%)	324	500	690	810	929
ECS NO. 5 (3%)	81	125	173	202	232
ECS NO. 6 (8%)	216	335	461	540	619
ECS NO. 7 (25%)	675	1045	1440	1685	1935
ECS NO. 8 (3%)	81	125	173	202	232

The foregoing costs are summarized for the LDV in Table 3-12, and for the MDV cases in Tables 3-13, 3-14, 3-15, and 3-16. In all cases, all fuel cost penalties were allocated to NO_x control.

Table 3-12. Cost Summary for LDV -- I_w = 4500 lb; 350-CID Engine

COST CATEGORY	CALSPAN No.						
	2	3	4	5	6	7	8
	IC/AI/EGR	OC/EGR	OC/RC	EFI/TRI	LTR	RTR	AC
OVERALL SYSTEM							
INITIAL COST	124	204	295	248	145	173	144
MAINTENANCE (Δ)	59	315	601	309	25	33	110
ΔFUEL COST (1)	135	135	324	81	216	675	81
TOTAL	318	654	1220	638	386	881	335
HC/CO RELATED							
INITIAL COST	85	165	166	187	106	134	105
MAINTENANCE (Δ)	51	307	307	228	17	25	102
ΔFUEL COST (1)	0	0	0	0	0	0	0
TOTAL	136	472	473	415	123	159	207
NO_x RELATED							
INITIAL COST	39	39	129	61	39	39	39
MAINTENANCE (Δ)	8	8	294	81	8	8	8
ΔFUEL COST (1)	135	135	324	81	216	675	81
TOTAL	182	182	747	223	263	722	128

(1) ALL FUEL COSTS ALLOCATED TO NO_x CONTROL

The costs shown are total delta system costs in order to fully account for the total cost of each ECS to the consumer. The one cost not included, certification costs, was assumed to be the same as current costs for LDV and HDV engine certification. Being total ECS costs, they also include the costs of the evaporative control system in all ECS. Since the evaporative control system was in all ECS systems it could have been omitted as a cost, however, the overall results would show similar trends.

In summary, the MDV costs are the same as the LDV costs, except for maintenance and fuel cost differentials occasioned by the different average lifetimes and average lifetime mileages. The MDV total

Table 3-13. Cost Summary for MDV No. 1 -- I_w = 6000 lb; 350-CID Engine

COST CATEGORY	CALSPAN No.						
	2	3	4	5	6	7	8
	IC/AI/EGR	OC/EGR	OC/RC	EFI/TRI	LTR	RTR	AC
OVERALL SYSTEM							
INITIAL COST	124	204	295	248	145	173	144
MAINTENANCE (Δ)	82	458	887	452	38	49	148
Δ FUEL COST (1)	209	209	500	125	335	1045	125
TOTAL	415	871	1682	825	518	1267	414
HC/CO RELATED							
INITIAL COST	85	165	166	187	106	134	105
MAINTENANCE (Δ)	69	445	445	329	25	36	135
Δ FUEL COST (1)	0	0	0	0	0	0	0
TOTAL	154	610	611	516	131	170	240
NO_x RELATED							
INITIAL	39	39	129	61	39	39	39
MAINTENANCE (Δ)	13	13	442	123	13	13	13
Δ FUEL COST (1)	209	209	500	125	335	1045	125
TOTAL	261	261	1071	309	387	1097	177

(1) ALL FUEL COSTS ALLOCATED TO NO_x CONTROL

Table 3-14. Cost Summary for MDV No. 2 -- I_w = 9000 lb; 350-CID Engine

COST CATEGORY	CALSPAN No.						
	2	3	4	5	6	7	8
	IC/AI/EGR	OC/EGR	OC/RC	EFI/TRI	LTR	RTR	AC
OVERALL SYSTEM							
INITIAL COST	124	204	295	248	145	173	144
MAINTENANCE (Δ)	82	458	887	452	38	49	148
Δ FUEL COST (1)	288	288	690	173	461	1440	173
TOTAL	494	950	1872	873	644	1662	465
HC/CO RELATED							
INITIAL COST	85	165	166	187	106	134	105
MAINTENANCE (Δ)	69	445	445	329	25	36	135
Δ FUEL COST (1)	0	0	0	0	0	0	0
TOTAL	154	610	611	516	131	170	240
NO_x RELATED							
INITIAL COST	39	39	129	61	39	39	39
MAINTENANCE (Δ)	13	13	442	123	13	13	13
Δ FUEL COST (1)	288	208	690	173	461	1440	173
TOTAL	340	340	1261	357	513	1492	225

(1) ALL FUEL COSTS ALLOCATED TO NO_x CONTROL

Table 3-15. Cost Summary for MDV No. 3 -- I_w = 11,000 lb; 350-CID Engine

COST CATEGORY	CALSPAN No.						
	2	3	4	5	6	7	8
	IC/AI/EGR	OC/EGR	OC/RC	EFI/TRI	LTR	RTR	AC
OVERALL SYSTEM							
INITIAL COST	124	204	295	248	145	173	144
MAINTENANCE (Δ)	82	458	887	452	38	49	148
ΔFUEL COST (1)	337	337	810	202	540	1685	202
TOTAL	543	999	1992	902	723	1907	494
HC/CO RELATED							
INITIAL COST	85	165	166	187	106	134	105
MAINTENANCE (Δ)	69	445	445	329	25	36	135
ΔFUEL COST (1)	0	0	0	0	0	0	0
TOTAL	154	610	611	516	131	170	240
NO_x RELATED							
INITIAL COST	39	39	129	61	39	39	39
MAINTENANCE (Δ)	13	13	442	123	13	13	13
ΔFUEL COST (1)	337	337	810	202	540	1685	202
TOTAL	389	389	1381	386	592	1737	254

(1) ALL FUEL COSTS ALLOCATED TO NO_x CONTROL

Table 3-16. Cost Summary for MDV No. 4 -- I_w = 14,000 lb; 350-CID Engine

COST CATEGORY	CALSPAN No.						
	2	3	4	5	6	7	8
	IC/AI/EGR	OC/EGR	OC/RC	EFI/TRI	LTR	RTR	AC
OVERALL SYSTEM							
INITIAL COST	124	204	295	248	145	173	144
MAINTENANCE (Δ)	82	458	887	452	38	49	148
ΔFUEL COSTS (1)	387	387	929	232	619	1935	232
TOTAL	593	1049	2111	932	802	2157	524
HC/CO RELATED							
INITIAL	85	165	166	187	106	134	105
MAINTENANCE (Δ)	69	445	445	329	25	36	135
ΔFUEL COST (1)	0	0	0	0	0	0	0
TOTAL	154	610	611	516	131	170	240
NO_x RELATED							
INITIAL	39	39	129	61	39	39	39
MAINTENANCE (Δ)	13	13	442	123	13	13	13
ΔFUEL COST (1)	387	387	929	232	619	1935	232
TOTAL	439	439	1500	416	671	1987	284

(1) ALL FUEL COSTS ALLOCATED TO NO_x CONTROL

costs increase with increasing I_w in accordance with the fuel economy versus I_w characteristics of Figure 2-3 (fuel economy decreases with increasing I_w).

3.4 EFFECT OF EMISSION CONTROL ON GASOLINE CONSUMPTION

To illustrate the relative effect of emission control fuel penalties when incorporated on LDVs and MDVs, a simple calculation was performed based on 1970 sales characteristics.

Figure 3-22 illustrates the total gallons used in one year by both LDVs and MDVs, based on the sales volume and fuel economy characteristics (mpg) shown. Also shown is the impact of powering all MDVs with diesel engines having a 50 percent fuel economy improvement over gasoline engines. While this is not considered a reasonable likelihood, it is shown merely to illustrate the relative effect. As can be seen, the consumption of gasoline by LDVs far overshadows MDV gasoline consumption. Emission control fuel economy penalties for LDVs would therefore be far more significant than corresponding MDV emission control fuel economy penalties.

Figure 3-23 shows the same information as Figure 3-22, but is plotted in terms of Δgal used per year.

Reference 3-1 is referred to for an analysis of total gasoline fuel consumption requirements as affected by the introduction of various ECSs and/or diesel engines in the MDV class on a scheduled basis.

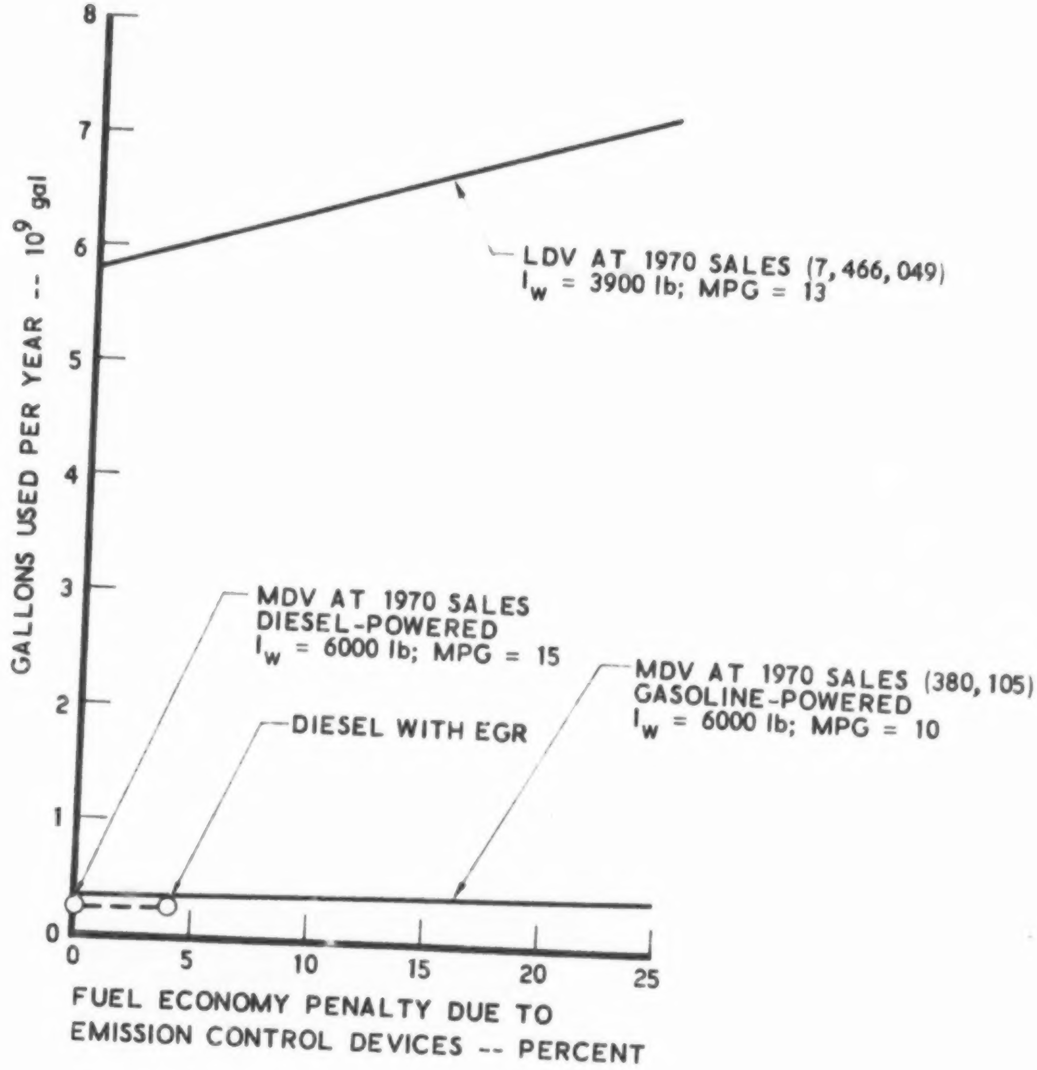

Figure 3-22. Effect of Emission Control Fuel Economy Reduction on Gasoline Consumption -- 1 yr only

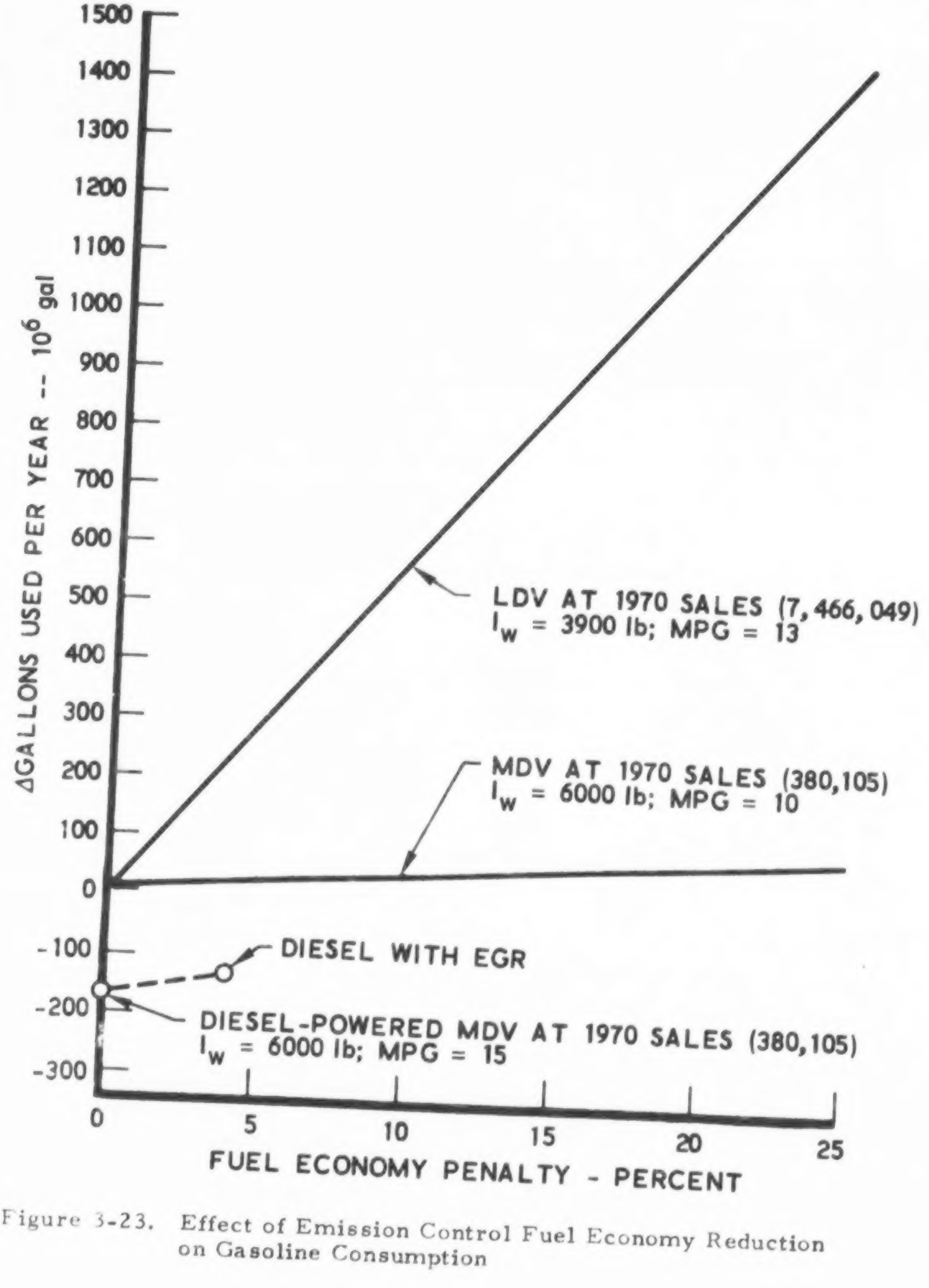

Figure 3-23. Effect of Emission Control Fuel Economy Reduction on Gasoline Consumption

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SECTION 4

MEDIUM-DUTY VEHICLE EMISSION CONTROL COST FACTORS

The comparison parameter selected to determine the relative cost-effectiveness between emission controls for LDVs, MDVs, HDVs, and stationary sources is the $/ton of pollutant removed over the vehicle and/or control system lifetime. In the case of mobile sources, cost factors were determined for the following pollutants and combinations: HC, CO, NO_x, and HC + CO + NO_x. As noted previously, mobile source pollutant reductions are based on two initial or baseline emission characteristics (prior to installation of ECS No. 2 through No. 8) for both LDVs and MDVs. In the case of LDVs, these baselines were:

a. The 1972 technology levels as evidenced by 1972 LDV certification averages.

b. The earlier, or 1968, technology levels as evidenced by 1968 passenger car emission levels.[1]

For MDVs, these baselines were:

a. The 1972 LDV technology levels extrapolated over MDV I_w range.

b. The earlier technology level as evidenced by the Calspan truck regression characteristics.

All of the above baselines were previously graphically illustrated in Figures 3-18, 3-19, 3-20. The following sections summarize and compare the resultant cost factors for LDVs and MDVs by various display techniques.

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[1] D. S. Kircher and D. P. Armstrong, Interim Report on Motor Vehicle Emission Estimation, EPA (October 1972).

4.1 THE MDV AND LDV COST FACTOR COMPARISONS

4.1.1 Compared by Emission Control System Type

Figures 4-1 through 4-7 illustrate the variance of emission control cost factor with MDV I_w for ECS No. 2 through ECS No. 8, when applied to engines conforming to 1972 LDV technology baseline characteristics. The symboled points represent the MDV cases of Table 2-1; the comparison LDV case at I_w = 4500 lb is also shown. The HC, CO, and HC + CO + NO_x cost factors decrease with increasing I_w and are less than the LDV cost factors of the same type. These cost factors would be expected to decrease as I_w increases, since the costs involved are nearly independent of I_w and the emission reductions increase in numerical value as I_w increases. This is because of the positive slope (relative to I_w) of the baseline emissions assumptions (Figures 3-18, 3-19, and 3-20). The effects of the "alternate" 1972 LDV technology CO baseline slope of Figure 3-19 are depicted in Figure 4-1. The absolute value of the cost factor (CO, HC + CO + NO_x) is higher (due to the lower slope of the alternate CO baseline); however, the MDV cost factors are still lower than for the LDV case. The NO_x cost factors, however, vary with MDV I_w discretely with ECS type and vary in absolute value from slightly below LDV values to slightly above LDV values. The shape of the NO_x cost factor curves is a result of the combined interactions of NO_x baseline emission level slope (Figure 3-20), variations in NO_x emission factor "R," and the shape of the fuel economy as a function of I_w characteristic selected in Figure 2-3 (decreasing rate of change of fuel economy as I_w increases).

Similar cost factor results are shown in Figures 4-8 through through 4-14 for ECS No. 2 through No. 8 when applied to engines conforming to the earlier technology emissions baseline of Figures 3-18, 3-19, and 3-20. On this basis of comparison, even the NO_x cost factor for MDVs is below the LDV value. This is because the MDV NO_x baseline emissions (Figure 3-20) are considerable higher than the LDV NO_x emission rate

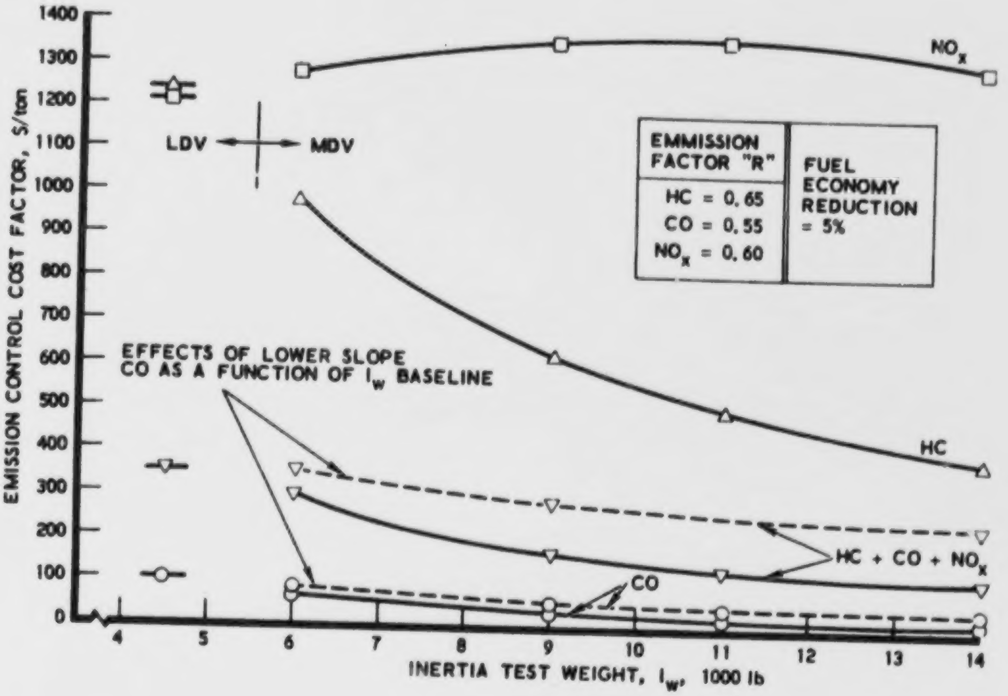

Figure 4-1. Cost Factors for Emission Control System No. 2 -- 1972 LDV Technology Baseline (EI + IC + QHI + AI + EGR)

selected as comparable in terms of technology level, thus giving greater NO_x reductions (for the same ECS type and NO_x "R" factor) and concomitant lower NO_x cost factors.

It should be recognized that the absolute level of any cost factor is a simple reflection of the values selected initially for baseline emissions and ECS cost characteristics. As discussed in Section 3.2.5, two emission level baselines were used in the present analysis to "bound" the problem. Cost factors based on the "earlier" technology baseline may be reasonably characteristic of applying ECS to the MDVs with HDV engines

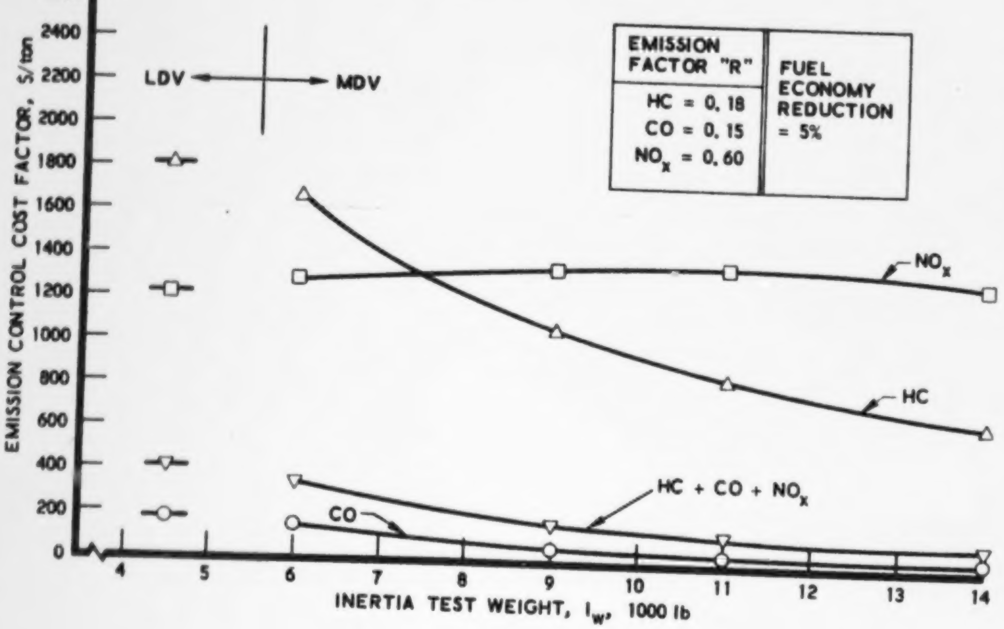

Figure 4-2. Cost Factors for Emission Control System No. 3 -- 1972 LDV Technology Baseline (EI + IC + QHI + AI + EGR + OC)

as modified to meet the first level of emission control (1969 to 1974 heavy-duty engine requirements). Cost factors based on the 1972 LDV extrapolated technology baseline may be reasonably characteristic of applying ECS to MDVs incorporating engines as modified to meet 1972 LDV certification levels. The exact cost factor for a given MDV engine combination would depend on the specific engine involved and the modifications made to it (combustion chamber, ignition timing, spark retard, etc.) prior to the addition of specific ECSs of the types examined herein (ECS No. 2 through No. 8).

Regardless of the basis of emission baseline comparison, however, it is clear that emission control of MDVs in terms of HC, CO, and HC + CO + NO_x cost factors, is more cost effective than when applying

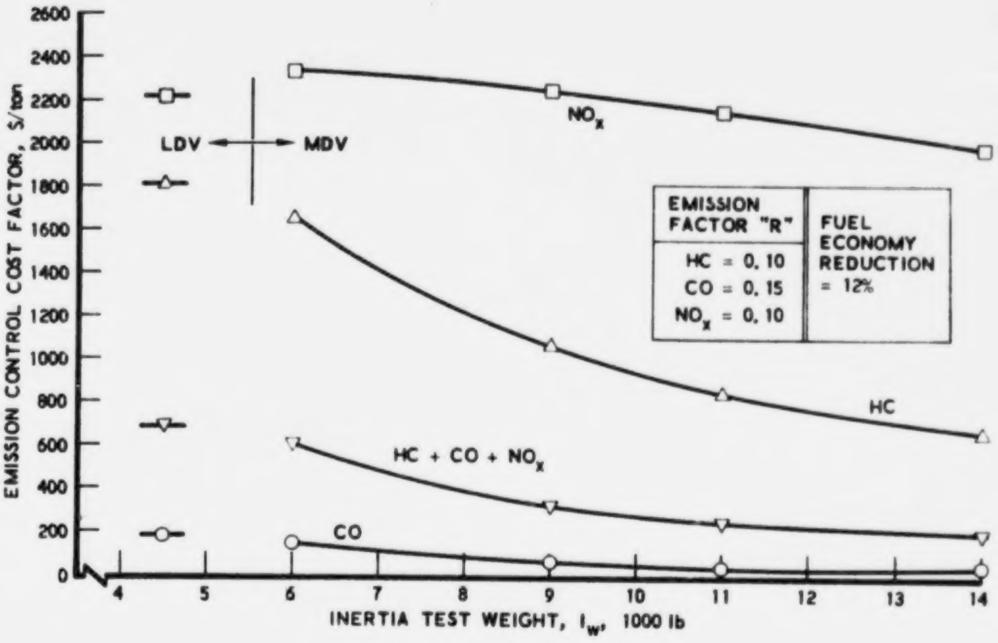

Figure 4-3. Cost Factors for Emission Control System No. 4 -- 1972 LDV Technology Baseline (EI + IC + QHI + RC + AI/CAI + OC)

similar controls to LDVs. This result occurs principally because of the higher MDV emission levels prior to adding a given ECS, and also results in the lower cost factors as I_W (or MDV GVW size) increases because the baseline emissions are greater with increasing I_W.

4.1.2 Compared as a Function of Percent Reduction in Emission Rate

Figures 4-15 through 4-18 redisplay the data of Figures 4-1 through 4-7 in terms of the variation of HC, CO, NO_x, and HC + CO + NO_x cost factors with percent reduction in emission rate when applying ECS No. 2 through ECS No. 8 to LDVs and MDVs characterized by the 1972 LDV technology baseline. These displays also allow comparisons between ECS

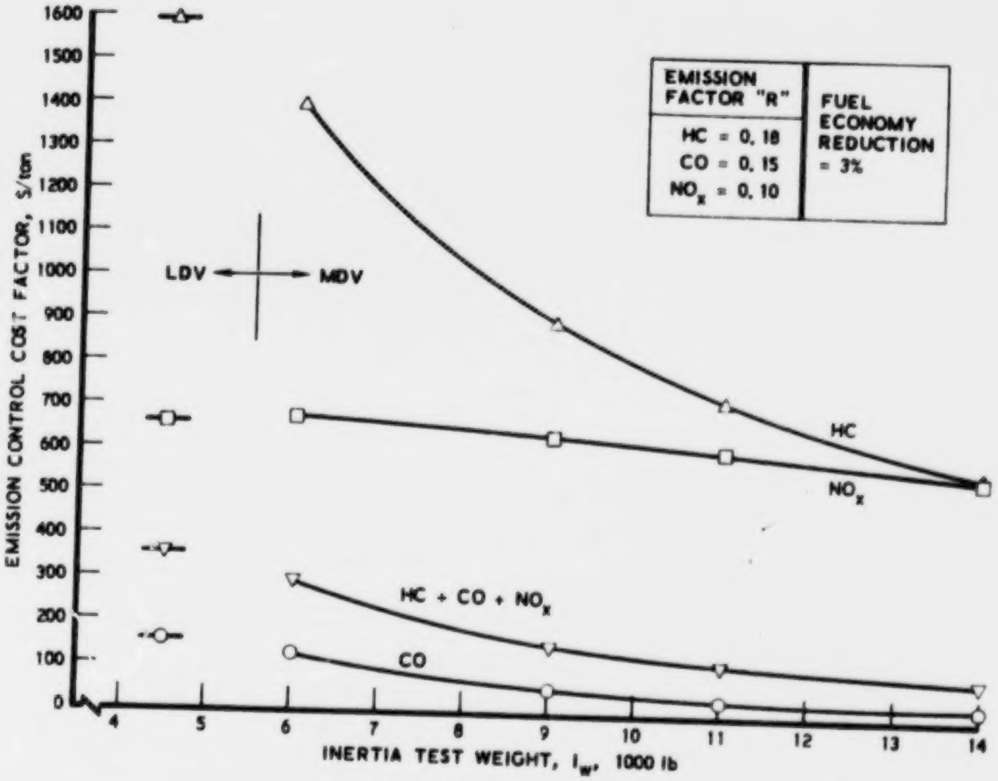

Figure 4-4. Cost Factors for Emission Control System No. 5 -- 1972 LDV Technology Baseline (EI + EFIC + EGR + RC/OC)

types based on the emission reduction level afforded and resultant cost factor. Again, in all cases, except NO_x (Figure 4-17), the MDV cost factors are lower than those for LDVs with the same ECS. It should be noted that ECS No. 8 (advanced lean carburetion with EGR) and ECS No. 5 (electronic fuel injection with tricomponent catalyst) are shown as a separate family of lines in Figure 4-17 because of their uniquely low NO_x cost factors that are, in turn, due primarily to low fuel economy losses (approximately 3 percent), coupled with relatively high NO_x reductions. Figure 4-17 also illustrates that MDV NO_x cost factors can be higher or lower than LDV NO_x cost factors, depending on the MDV I_w value and/or the specific ECS installed.

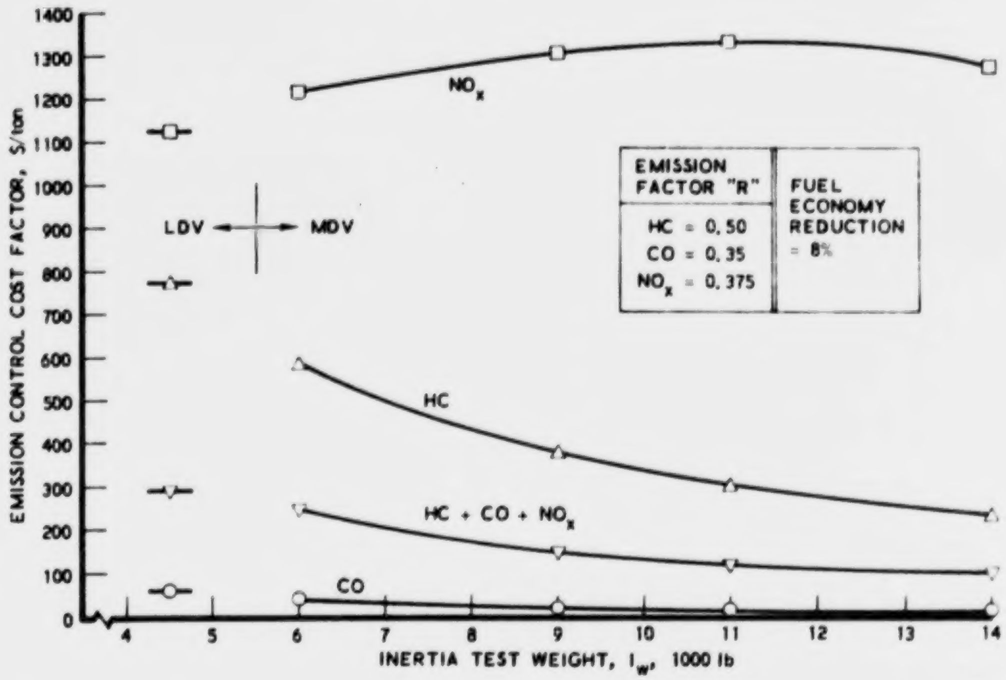

Figure 4-5. Cost Factors for Emission Control System No. 6 -- 1972 LDV Technology Baseline (EI + IC + QHI + EGR + LTR)

Figures 4-19, 4-20, and 4-21 similarly redisplay the data of Figures 4-8 through 4-14 (earlier technology baseline emissions) for HC, CO, and NO$_x$ cost factors. Here, as mentioned previously, all MDV cost factors (including NO$_x$) are lower than the correspondingly equipped LDV.

Attention is redrawn at this point to the method of apportionment of ECS costs to HC, CO, and NO$_x$ (see Section 3.3.2). All emission control cost factors are directly proportional to the costs assigned to each emission constituent. Therefore, the cost factor variations between ECSs shown in Figures 4-15 through 4-21 are reflections of the original cost apportionment assumptions. Different assumptions would result in slightly different cost factor variation patterns between the various ECSs. For example, if the evaporative control system costs were excluded from the

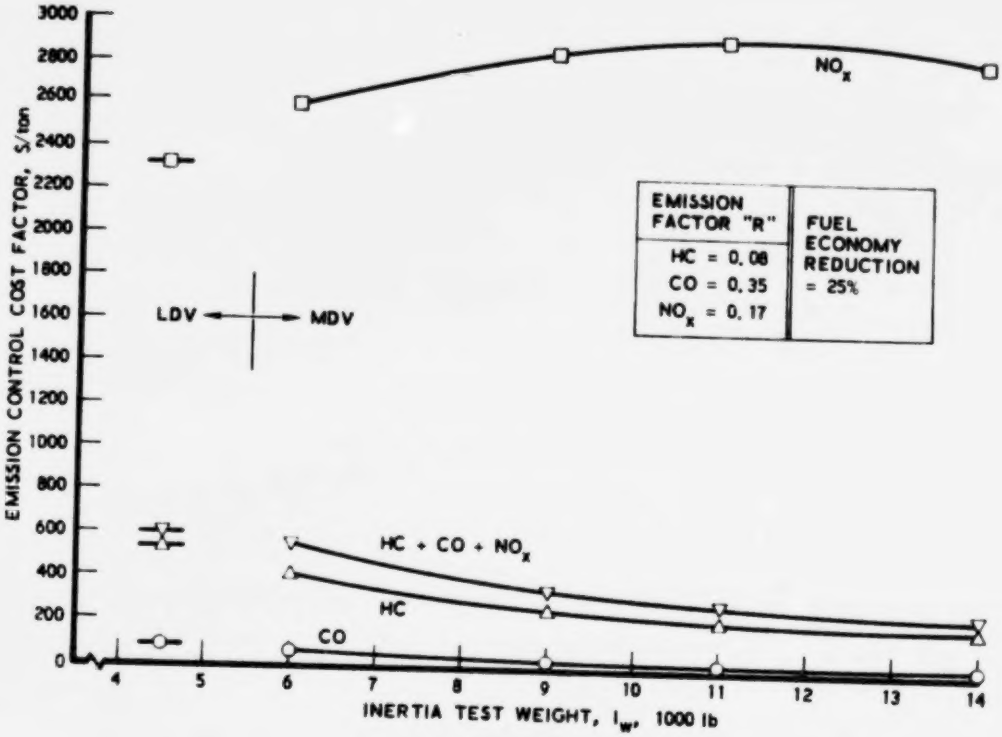

Figure 4-6. Cost Factors for Emission Control System No. 7 -- 1972 LDV Technology Baseline (EI + FC + EGR + AI + RTR)

cost factor calculations, all HC and CO cost factors for all ECSs in Figures 4-15 through 4-21 would be lower (by a constant amount) than those values shown; however, the relative relationship between the HC and CO cost factors for the various ECSs would remain as illustrated. This is shown in Figure 4-22, which is similar to Figure 4-15 (HC cost factor, 1972 LDV Technology Baseline) except for lower cost factor values occasioned by the deletion of evaporative control system costs.

4.1.3 The MDV and LDV Cost Factor Summary

As graphically illustrated in Figures 4-1 through 4-21, for the same ECS, MDVs have HC, CO, and HC + CO + NO$_x$ cost factors that

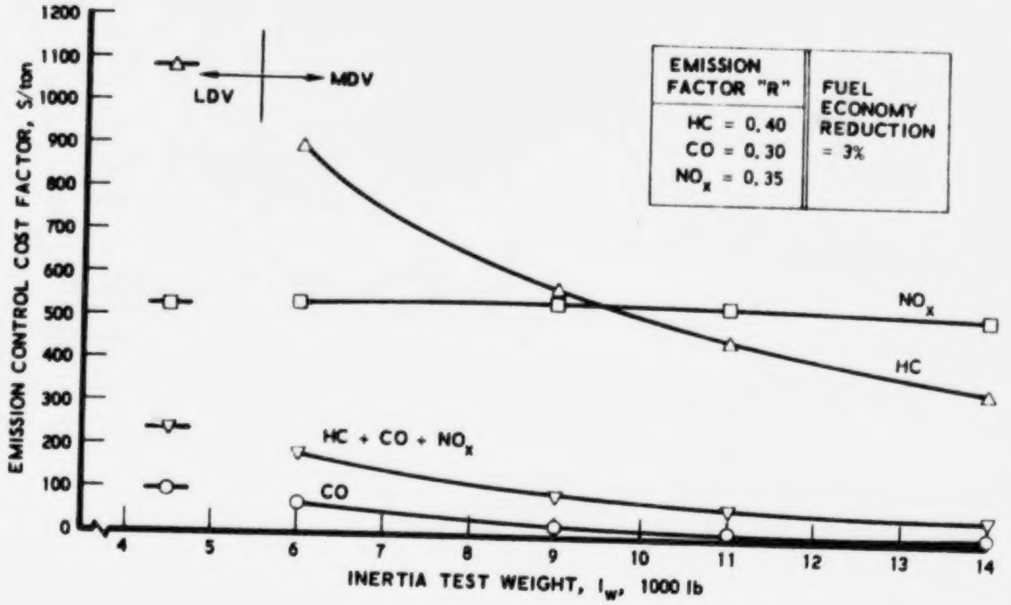

Figure 4-7. Cost Factors for Emission Control System No. 8 -- 1972 LDV Technology Baseline (EI + FIC + IQHI + AI + EGR)

can range from approximately equal to LDV cost factors at the I_w = 6000 lb level to considerably less than LDV values at the I_w = 14, 000 lb level.

The MDVs have NO_x cost factors that can be somewhat above LDV NO_x cost factors when comparing on the 1972 LDV technology baseline, but that are substantially below LDV values when compared on the earlier technology baseline.

The cost factor variability with ECS type is wide (Figures 4-15 through 4-21); therefore, caution should be observed when attempting to compare ECS on the basis of discrete cost factor characteristics (HC, CO, or NO_x).

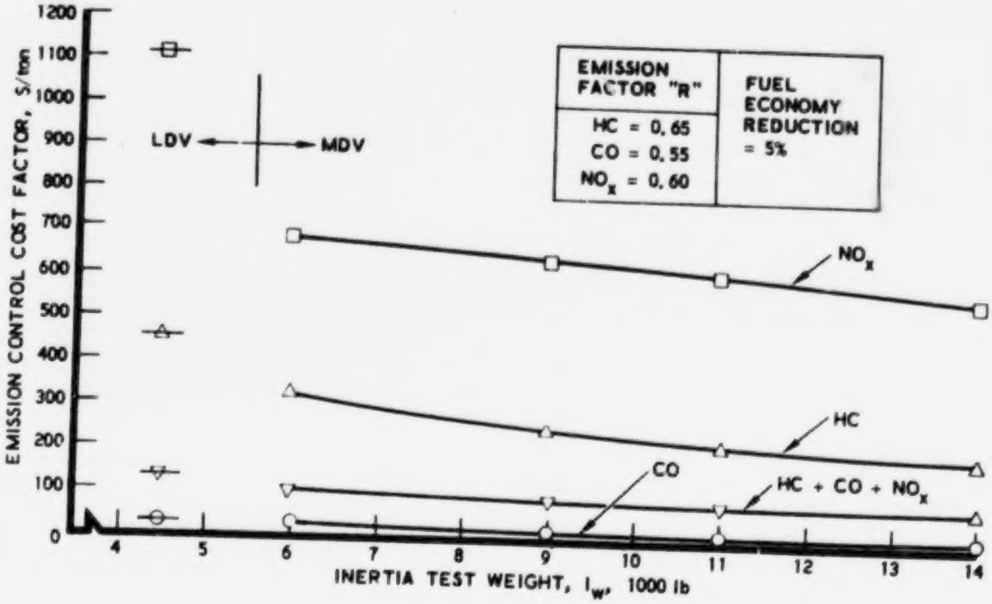

Figure 4-8. Cost Factors for Emission Control System No. 2 -- Earlier Technology Baseline (EI + IC + QHI + AI + EGR)

4.2 THE MDV AND LDV COST FACTOR CORRELATIONS

A brief examination and analysis were made to determine if the cost factors developed in Section 4.1 would further correlate. The correlation parameter selected was the emission rate, in gm/mi, which resulted after applying an ECS to an LDV or MDV. The emission baseline selected for this correlation exercise was the extrapolated 1972 LDV technology baseline.

The results are shown in Figures 4-23 and 4-24 for the LDV, and in Figures 4-25 through 4-28 for the MDV at I_W values of 6000 and 9000 lb. These cost factors are not simple functions of emission rates for different control systems. For example, the points shown for ECS No. 2 do not lie on the correlation curves drawn, as would be expected by anomalies previously shown in Figures 4-15 through 4-21. As shown in

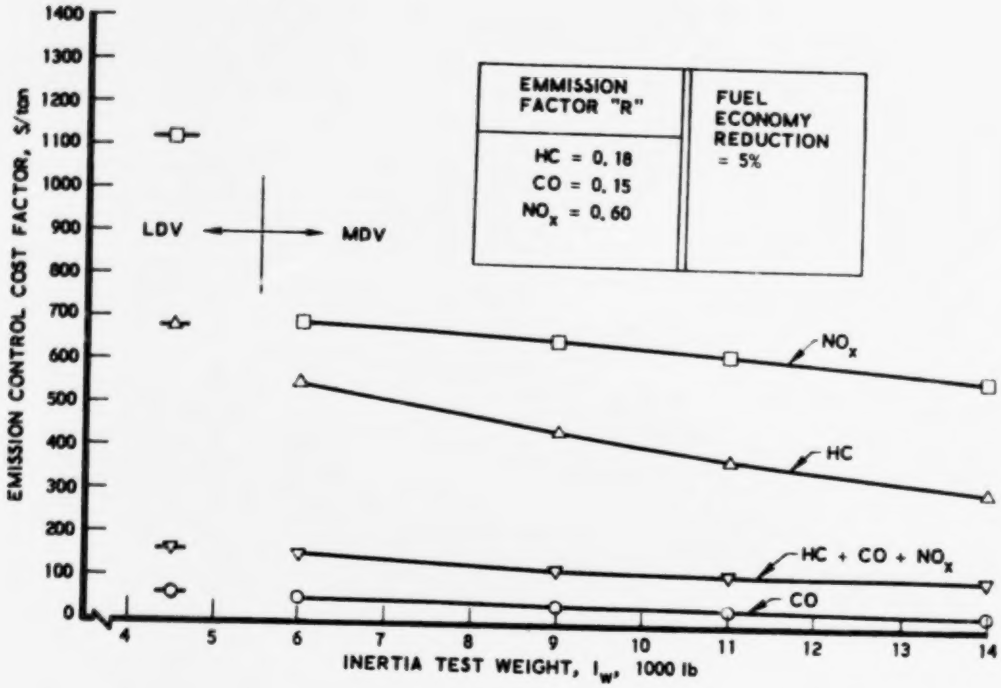

Figure 4-9. Cost Factors for Emission Control System No. 3 -- Earlier Technology Baseline (EI + IC + QHI + EGR + AI + OC)

Figure 4-23, correlation lines (lines drawn from the uncontrolled emission rate point through the ECS cost factor data points on a best-fit basis) for CO and HC + CO reasonably encompass the spectrum of ECSs shown. In the case of HC + CO + NO_x, two deviations or anomalies from a single characteristic are present. First, ECS No. 7 (rich thermal reactor) does not correlate, presumably because of its very high fuel economy penalty for NO_x control (approximately 25 percent). Second, ECS No. 5 (electronic fuel injection with tricomponent catalyst) and ECS No. 8 (advanced lean carburetion with EGR) require a distinct correlation line. This characteristic was previously described in terms of their very low cost factors for NO_x control (Figures 4-17 and 4-21).

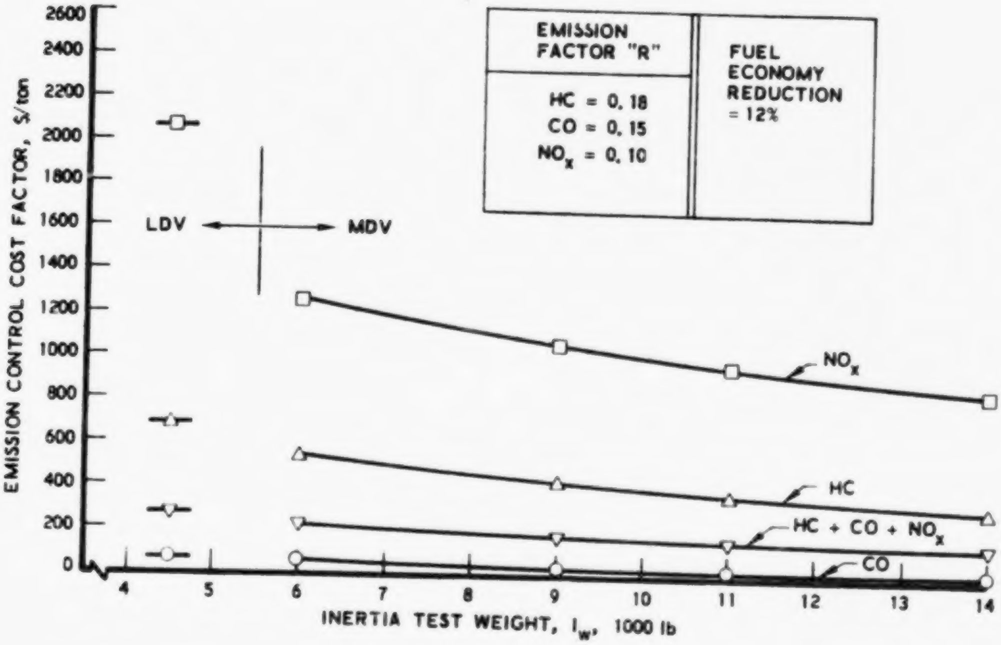

Figure 4-10. Cost Factors for Emission Control System No. 4 -- Earlier Technology Baseline (EI + IC + QHI + EGR + RC + AI/CAI + OC)

As shown in Figure 4-24, this same characteristic of ECS No. 5 and No. 8 requires dual correlation lines for NO_x control. Here, however, ECS No. 7 does correlate fairly well in terms of NO_x. For the HC case, a good single correlation line is observed, except for the single instance of ECS No. 7 whose extremely high capability for HC reduction (92 percent) requires that it represent a second correlation characteristic.

Similar characteristic correlation lines for MDVs at I_w = 000 and 9000 lb are developed in Figures 4-25 through 4-28. In all cases (LDV and MDV), the same ECS types are used as the basis for constructing the correlation lines. The general shape and degree of correlation for the MDVs are similar to the LDV case, as would be expected in the absence of unforeseen anomalies.

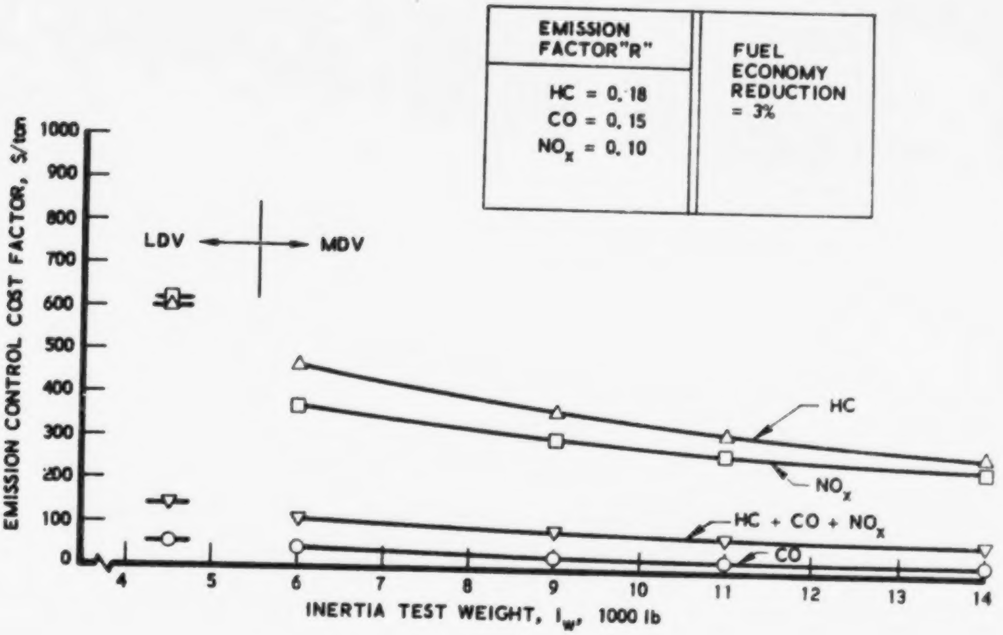

Figure 4-11. Cost Factors for Emission Control System No. 5 -- Earlier Technology Baseline (EI + EFIC + EGR + RC/OC)

The correlations attempted and shown in the figures are general, but they do characterize useful trend information. Thus, comparisons made between LDVs and MDVs using the same ECS data points for correlation curves should be reasonable.

4.3 SENSITIVITY OF COST FACTOR VALUES TO ASSUMPTIONS

As outlined in previous sections, both a variety and a large number of assumptions were required to compute LDV and MDV emission control cost factors. Obviously, the two principal assumptive areas were control system related costs and baseline or prior-to-control-addition emission level characteristics.

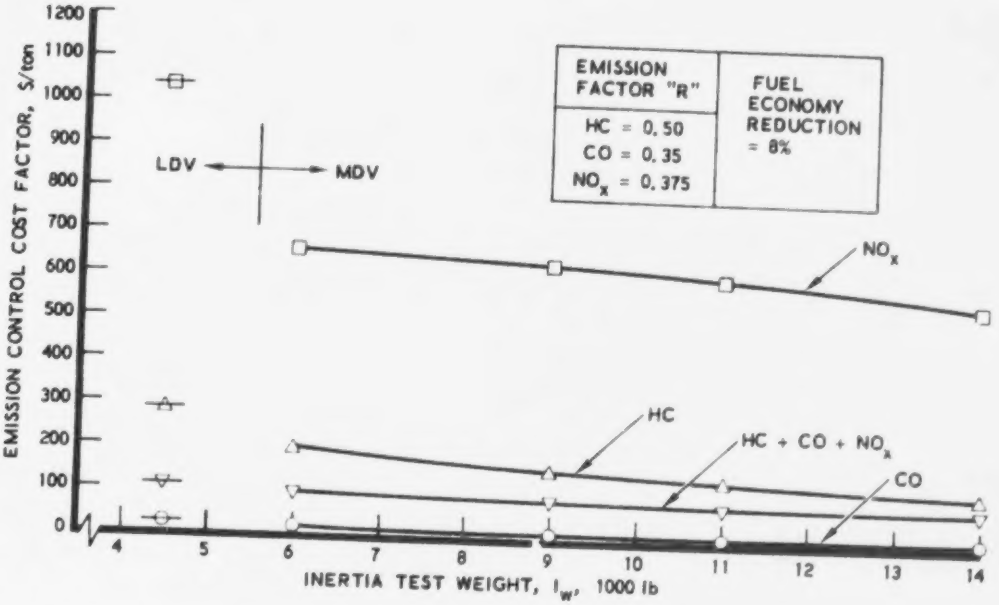

Figure 4-12. Cost Factors for Emission Control System No. 6 -- Earlier Technology Baseline (EI + IC + QHI + EGR + LTR)

With regard to the ECS costs, the resultant cost factors shown are directly proportional to ECS assumptions in terms of absolute value. For comparison purposes, however, the same discrete cost assumptions were used in building up total ECS costs for both LDVs and MDVs. The two subareas of dissimilarity (fuel economy as a function of I_w, and total vehicle lifetime) are based on the best available data, and also have a lesser effect on the resultant cost factor values.

In the area of baseline emission level characterization, it was shown (Section 3.2) that selecting a single such characteristic for MDVs was very difficult due to the fact that MDVs incorporate HDV engines which are regulated as to emission control levels by test procedures which have not been adequately correlated to on-the-road emissions (gm/mi). Therefore, two emission baselines were selected to encompass the spectrum of reasonably-anticipated MDV engine characteristics. One baseline

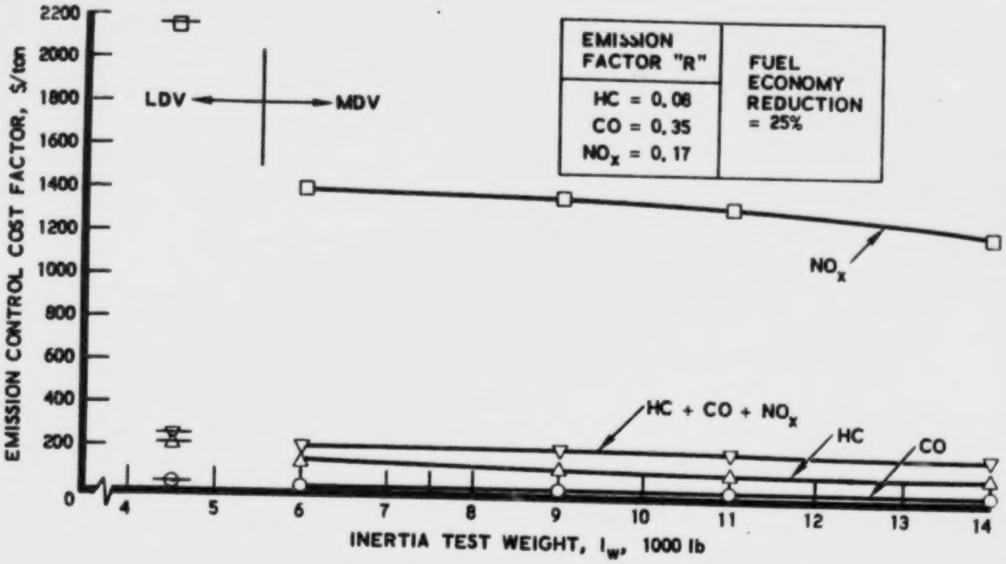

Figure 4-13. Cost Factors for Emission Control System No. 7 -- Earlier Technology Baseline (EI + FC + EGR + AI + RTR)

corresponded to the recent MDV truck correlation developed by Calspan for EPA. The second corresponded to the projected situation where MDV engines had reached the same technological status as 1972 LDV engines with combustion chamber modifications, ignition timing changes, and retarded spark. The baseline emission level used has a marked effect on the absolute cost factor values; therefore, unless other technical realities dictate otherwise, one should use the same technological basis when comparing LDVs to MDVs. In this latter context, for example, it may be perfectly valid or better to compare MDV cost factors based on the earlier technology baseline with LDV cost factors based on 1972 LDV certification levels. This follows from the fact that the LDV case is an accomplished reality; whereas the MDV engine progression to 1972 LDV technology capability is an assumptive and as yet unrealized condition. Thus, comparisons on this latter basis may

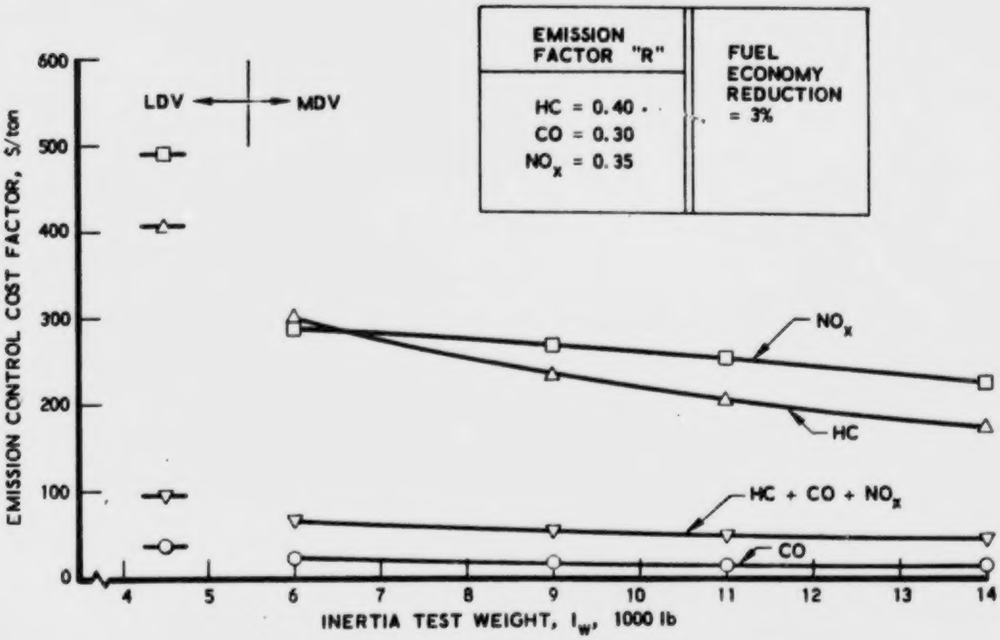

Figure 4-14. Cost Factors for Emission Control System No. 8 -- Earlier Technology Baseline (EI + FIC + IQHI + AI + EGR)

more properly represent the cost of attaining specified emission level reductions with LDVs vs. MDVs, starting with presently demonstrated capabilities.

The specific values attributed to HC, CO, and NO_x are uniquely and directly related to the manner of allocating costs to HC, CO, and NO_x as described in Section 3. 3. 2. When better techniques are developed for apportioning ECS costs to individual exhaust emission constituents, the individual cost factors developed herein should be recalculated. However, in terms of comparing LDVs to MDVs, this variability is of lesser importance since the same assumptions were made for both LDVs and MDVs.

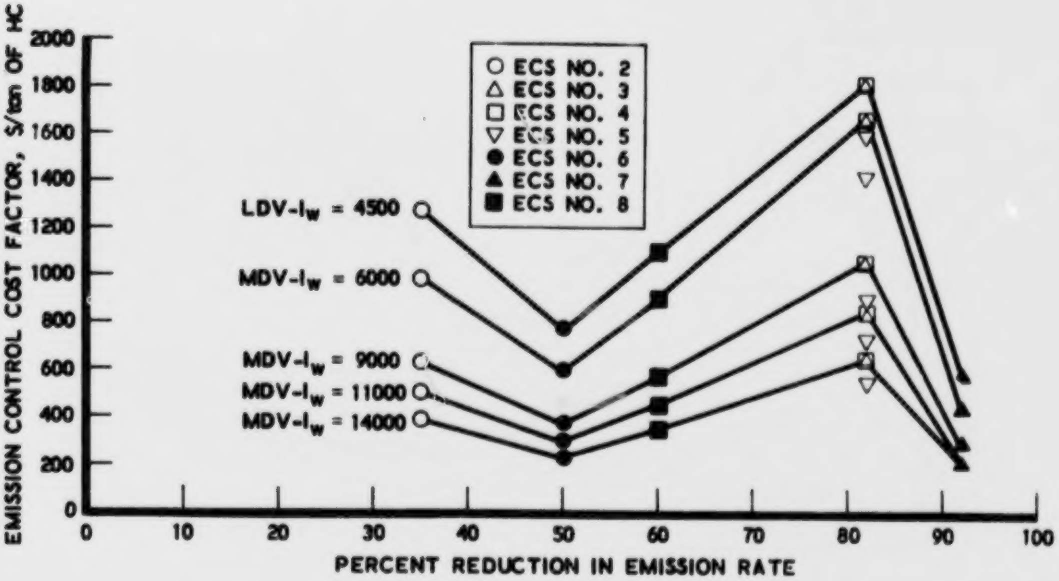

Figure 4-15. The MDV/LDV HC Cost Factor Comparison -- 1972 LDV Technology Baseline

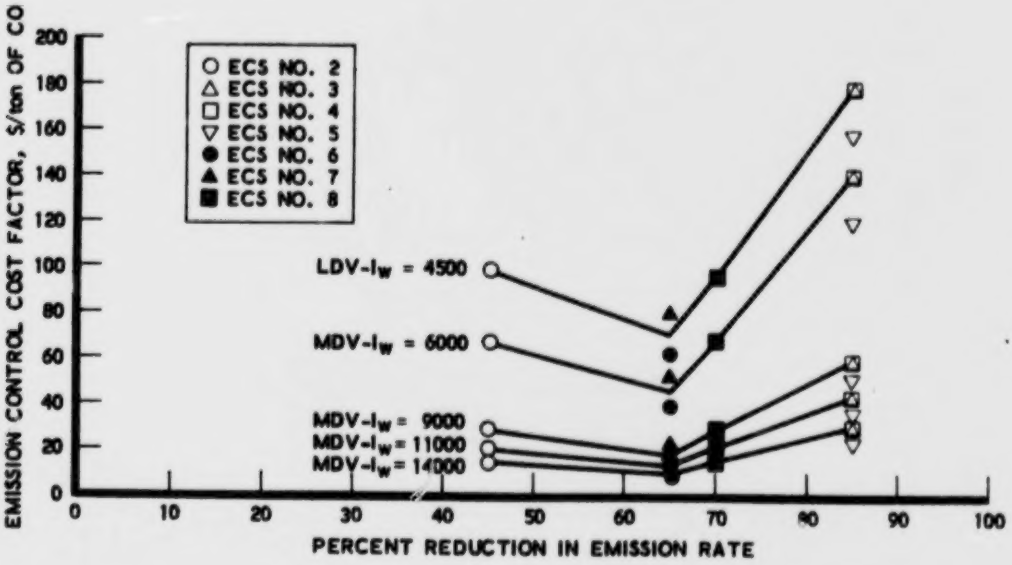

Figure 4-16. The MDV/LDV CO Cost Factor Comparison -- 1972 LDV Technology Baseline

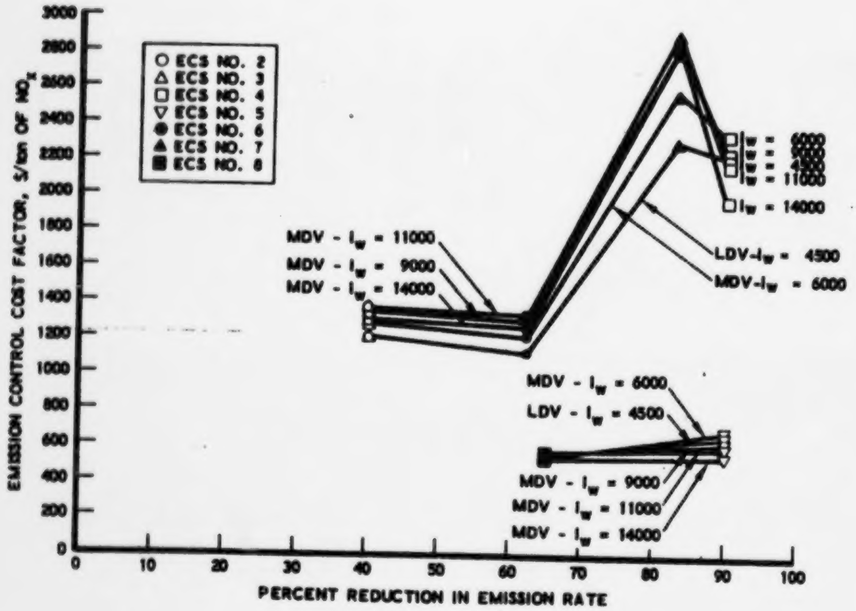

Figure 4-17. The MDV/LDV NO_x Cost Factor Comparison -- 1972 LDV Technology Baseline

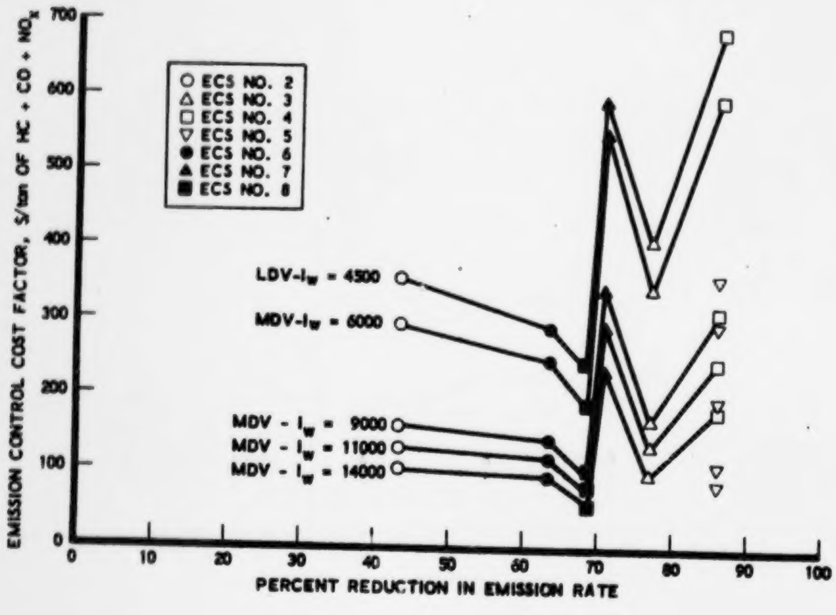

Figure 4-18. The MDV/LDV HC + CO + NO_x Cost Factor Comparison -- 1972 LDV Technology Baseline

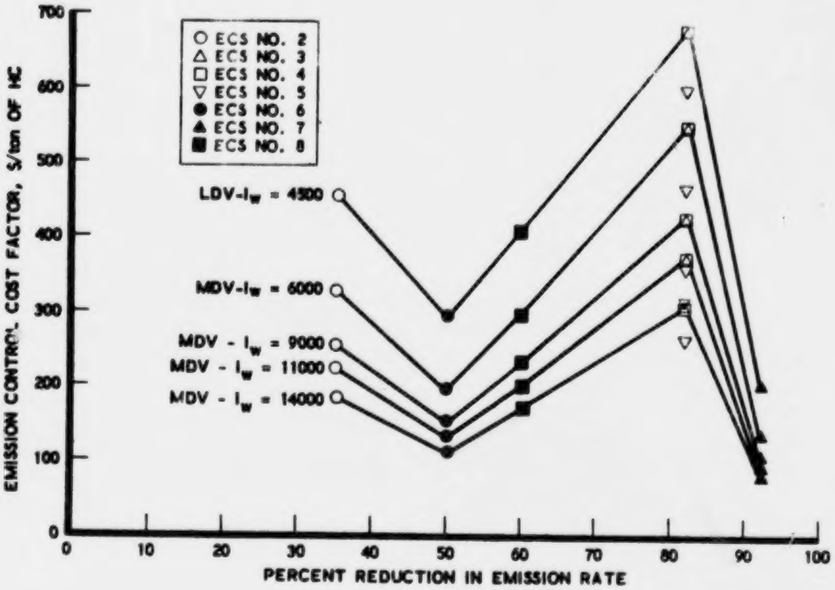

Figure 4-19. The MDV/LDV HC Cost Factor Comparison -- Early Technology Baseline

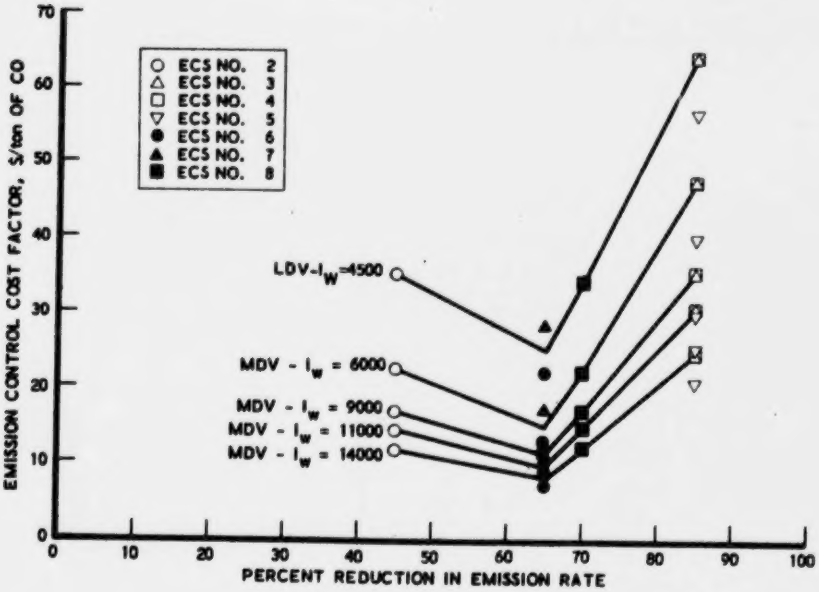

Figure 4-20. The MDV/LDV CO Cost Factor Comparison -- Early Technology Baseline

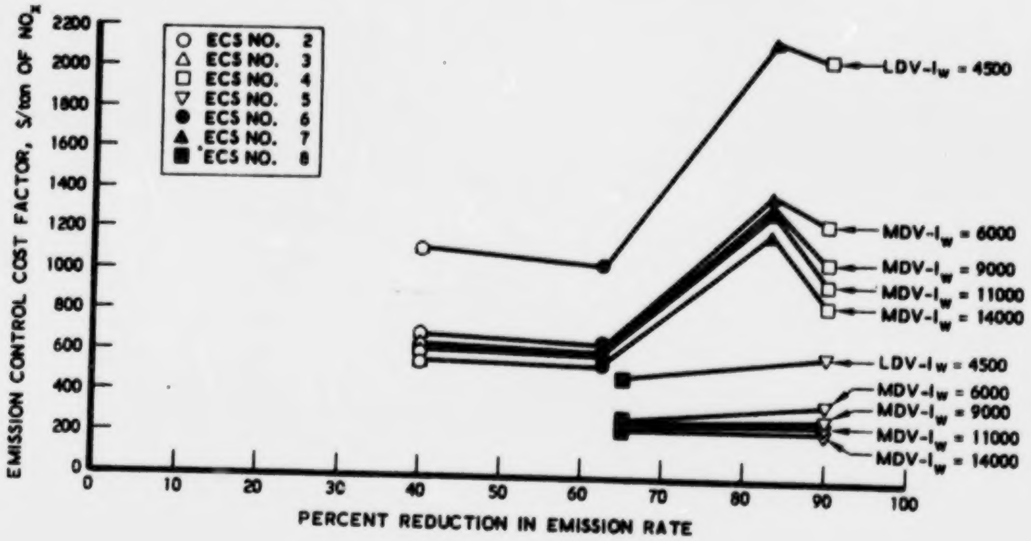

Figure 4-21. The MDV/LDV NO$_x$ Cost Factor Comparison -- Early Technology Baseline

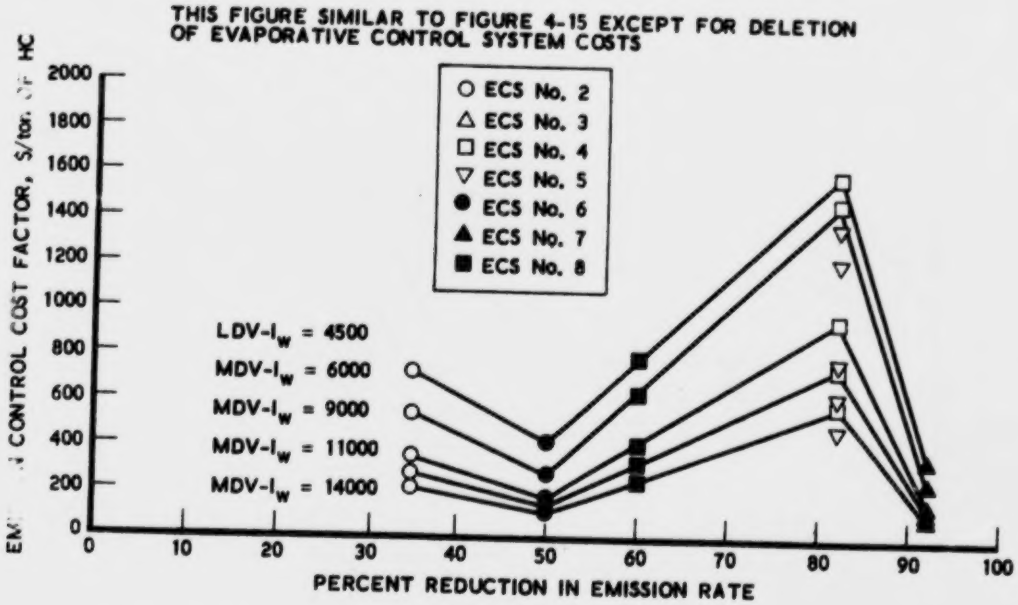
THIS FIGURE SIMILAR TO FIGURE 4-15 EXCEPT FOR DELETION OF EVAPORATIVE CONTROL SYSTEM COSTS

Figure 4-22. The MDV/LDV HC Cost Factor Comparison with Evaporative Control System Costs Deleted -- 1972 LDV Technology Baseline

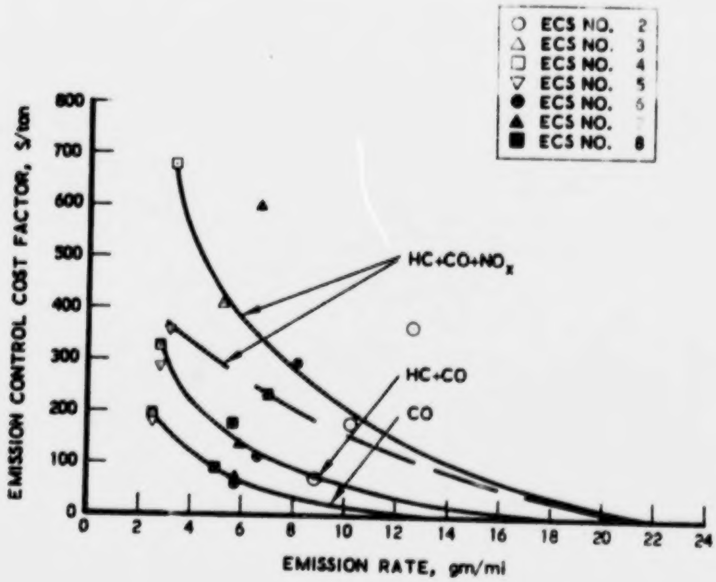

Figure 4-23. The LDV Emission Control Cost Factors for CO, HC + CO, and HC + CO + NO$_x$ -- 1972 LDV Technology Baseline (I_w = 4500 lb)

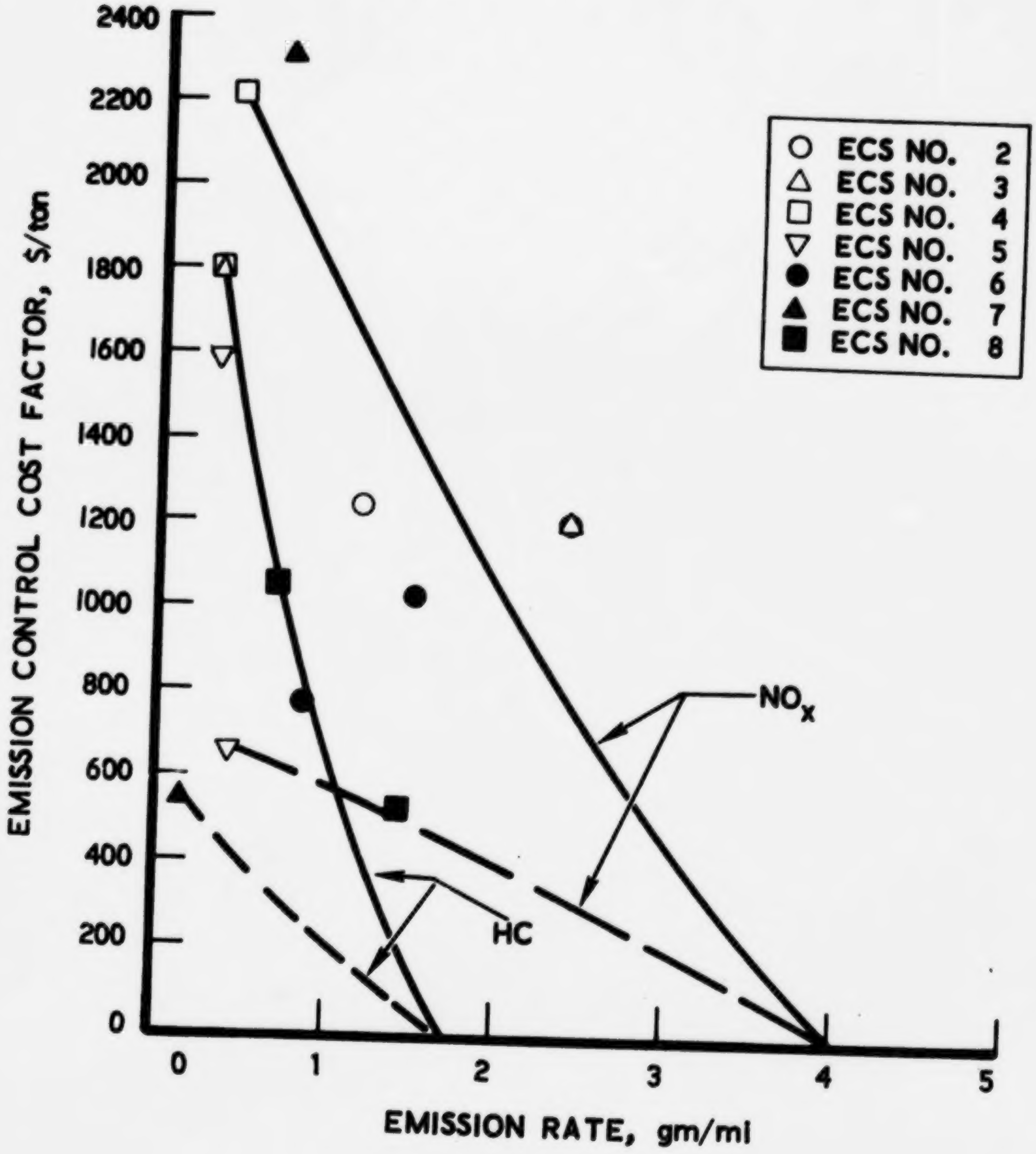

Figure 4-24. The LDV Emission Control Cost Factors for HC and NO$_x$ -- 1972 LDV Technology Baseline (I_w = 4500 lb)

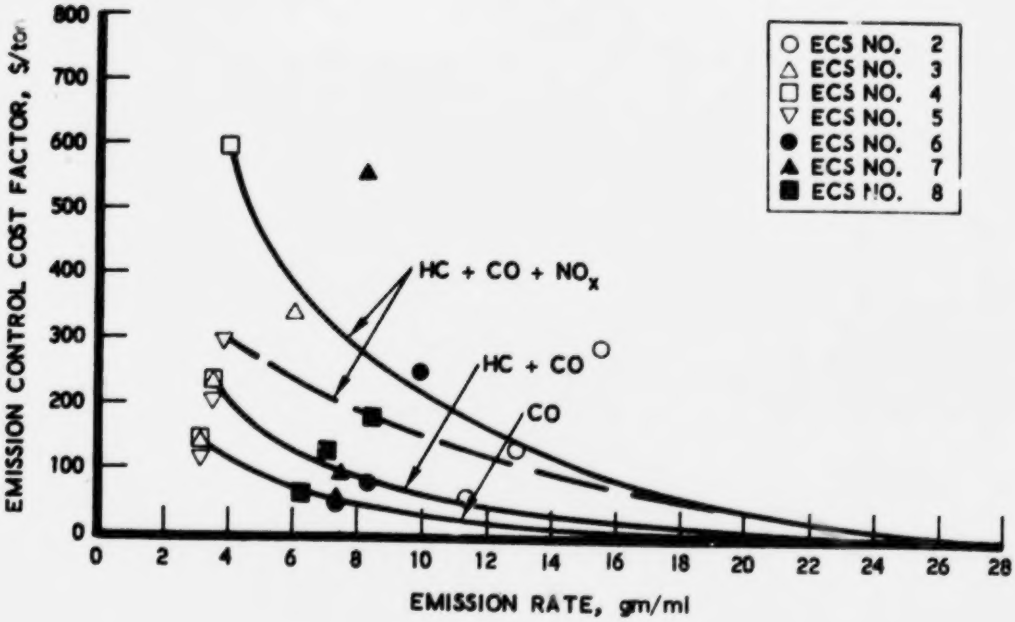

Figure 4-25. The MDV Emission Control Cost Factors for CO, HC + CO, and HC + CO + NO$_x$ -- 1972 LDV Technology Baseline (I_w = 6000 lb)

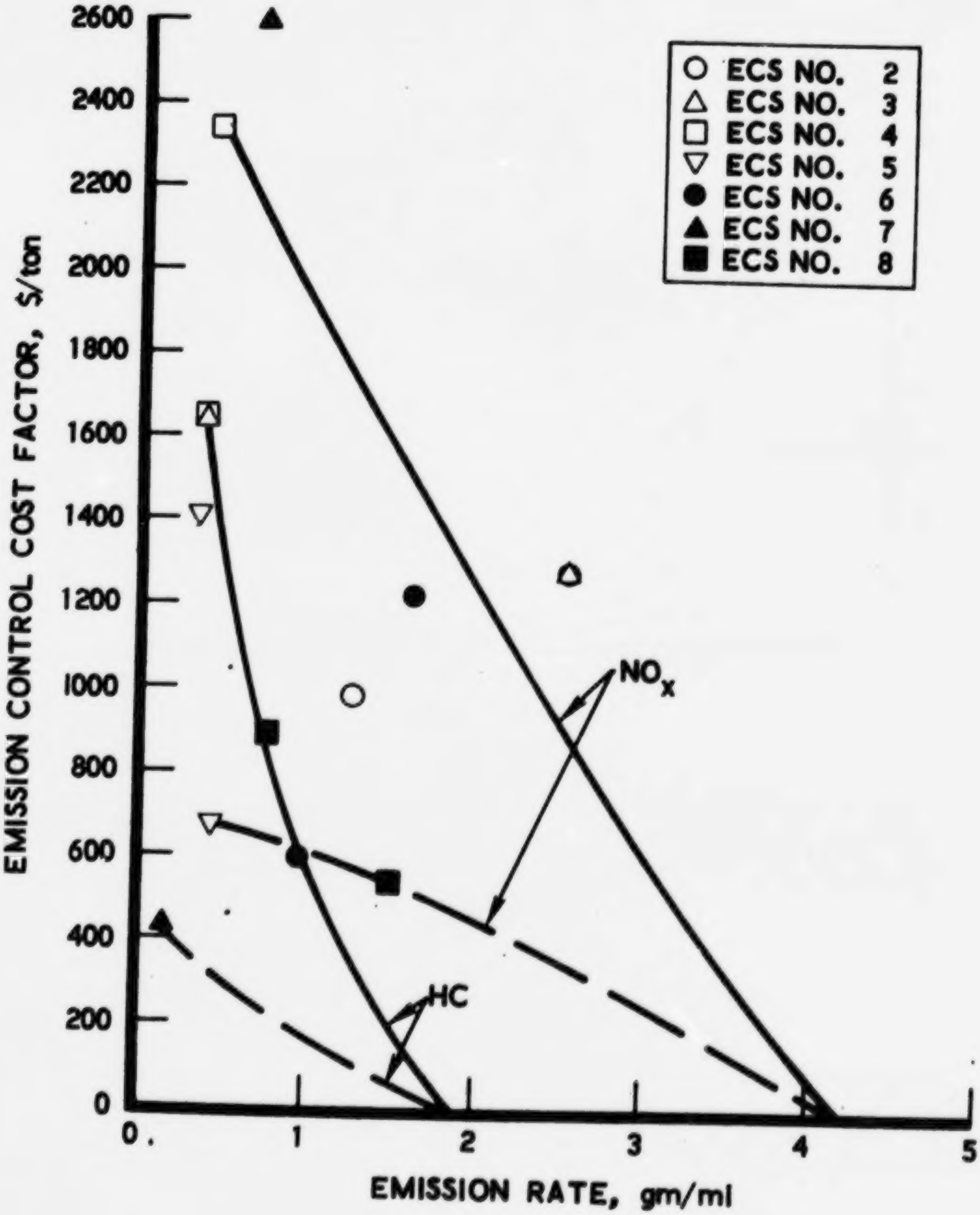

Figure 4-26. The MDV Emission Control Cost Factors for HC and NO_x -- 1972 LDV Technology Baseline (I_w = 6000 lb)

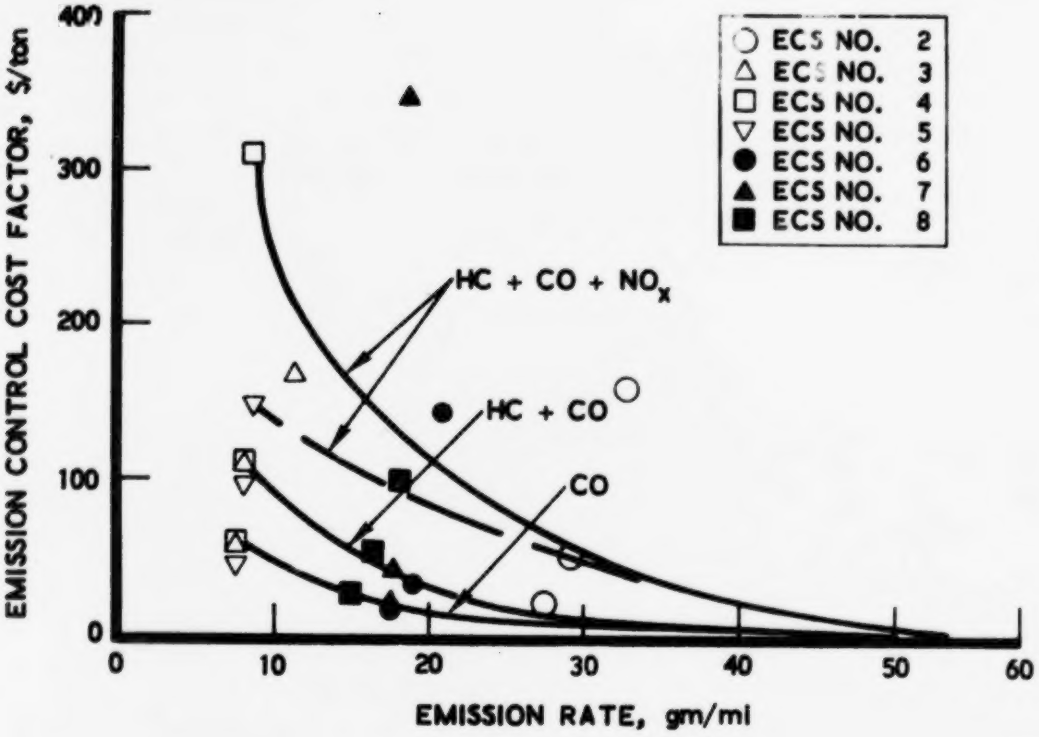

Figure 4-27. The MDV Emission Control Cost Factors for CO, HC + CO, and HC + CO + NO$_x$ -- 1972 LDV Technology Baseline (I_w = 9000 lb)

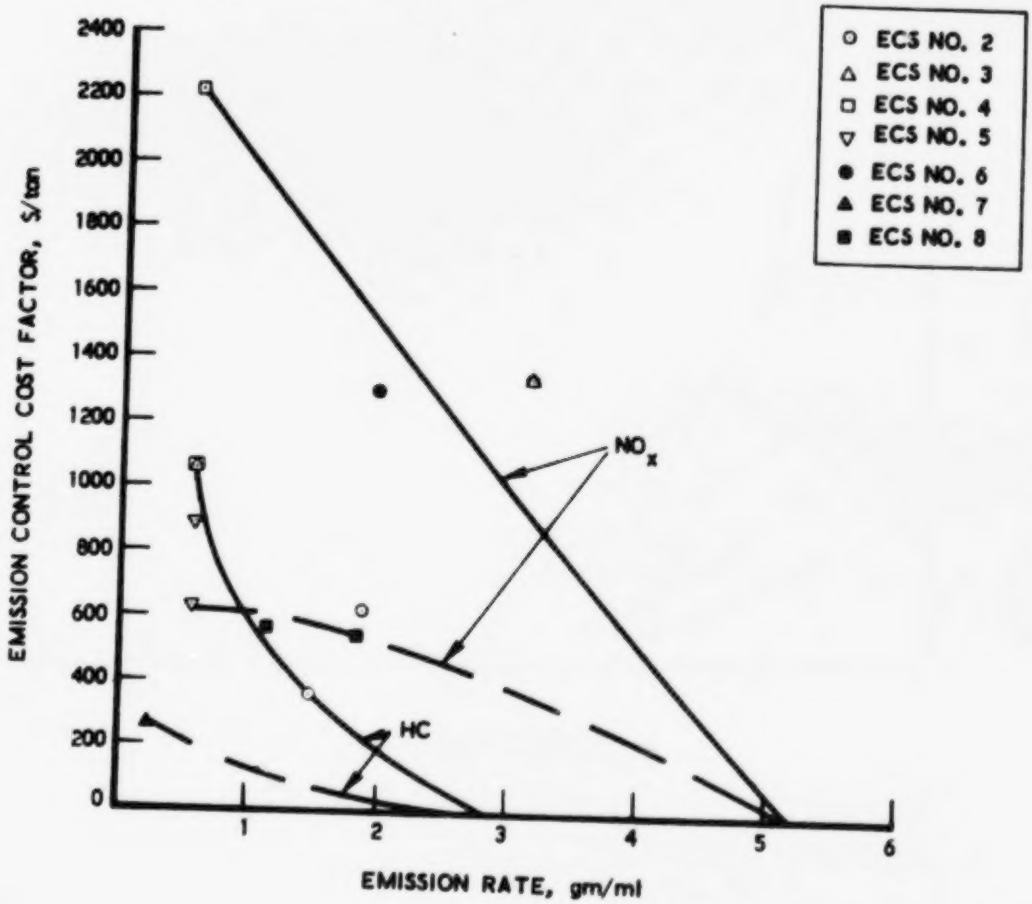

Figure 4-28. The MDV Emission Control Cost Factors for HC and NO_x -- 1972 LDV Technology Baseline (I_w = 9000 lb)

SECTION 5

HEAVY-DUTY VEHICLE COST COMPARISONS

A brief analysis of HDV emission control cost factors was made to be able to compare cost factors for the principal sources in the mobile source spectrum (LDVs, MDVs, and HDVs). The following sections summarize the cases examined, costs, assumptions made, and significant results.

5.1 CASES EXAMINED

A single HDV size (22,600-lb GVW) was selected for analysis. This GVW is the approximate sales-weighted average for trucks with GVWs above 14,000 lb (based on 1970 truck sales distribution by GVW from Ref. 5-1, trucks above 33,000-lb GVW were averaged at 35,000-lb GVW value). Based on the GVW as a function of I_w correlation of Figure 2-2, at one-half payload capacity, the I_w of this 22,600-lb GVW vehicle is approximately 15,000 lb.

A gasoline and a diesel engine were considered as power plants for the HDV case. The gasoline engine selected was a 454-CID, which was considered sufficiently representative of HDV engines for comparison purposes. The ECS Nos. 2, 3, 6, and 8 (as described in Tables 3-1 and 3-2) were selected for addition to the baseline 454-CID engine for emission control cost factor calculations.

Both direct injection and prechamber diesel engines were considered for a 680-CID engine. Although the displacement of diesel engines compared with gasoline engines for the same power application vary somewhat depending upon the type and vehicle application, the 1.5 ratio used herein (diesel CID = 1.5 × gasoline CID) is considered adequate for comparative purposes. The only ECS considered for the diesel engine was an EGR;

the diesel engine itself has low HC and CO emission rates, when compared with an uncontrolled gasoline engine.

The previously developed (Section 3. 3. 1 and Figure 3-21) gasoline engine lifetime values of 12.6 years and 130,000 mi were used for cost amortization. For the diesel, an engine lifetime of 12.6 years and 475,000 mi was selected.

5. 2 EMISSION CONTROL COSTS

A summary is presented in Tables 5-1 and 5-2 of initial hardware costs and lifetime maintenance costs for the gasoline-powered HDV. These costs are based on the same characteristics and assumptions as previously shown and developed for the LDV and MDV cases presented in Section 3. 3. 2. Therefore, cost differences between HDV and MDV cases are a result of either the difference in lifetime mileage (130,000 and 110,000, respectively) or the difference in CID-related ECS costs (thermal reactor costs and catalytic converter costs), which are a function of engine displacement (Ref. 5-2).

Three different methods were considered in estimating the cost differences between the HDV gasoline and diesel engines, as summarized in Table 5-3. In method 1, delta cost increments were summed (as shown) to arrive at a total delta cost of the diesel engine. The structure, brakes, and power steering delta costs are from Ref. 5-2, and the $800 (cost delta of 680-CID diesel over 680-CID gasoline engine) and $700 (cost delta of 680-CID gasoline engine over 454-CID gasoline engine) cost deltas are based on extrapolations of characteristics developed in Ref. 5-2, as noted in the table. This method resulted in a total cost delta of $1725.

In method 2, characteristic $/hp values from Ref. 5-3 were used to develop a delta cost value of $1670 for the diesel engine only (no allowances for vehicle structure or accessory changes). In method 3, list price differentials from Ref. 5-4 were used as characteristic of the HDV class under investigation. The three cases listed in Table 5-3, resulted in

Table 5-1. ECS Initial Cost Summary -- HDV; 454-CID Engine

COMPONENTS	CALSPAN No.			
	2	3	6	8
ELECTRONIC IGNITION (EI)[1]	20	20	20	20
QUICK HEAT INTAKE (QHI)	5	5	5	5
IMPROVED CARBURETION (IC)	10	10	10	
ADVANCED CARBURETION (AC)				30
EXHAUST GAS RECIRCULATION (EGR)[2]	30	30	30	30
THERMAL REACTOR (TR)			73	
AIR INJECTION (AI)	38	39		38
OXIDIZING CATALYST (OC)		84		
CATALYST BYPASS		10		
EVAPORATIVE CONTROL SYSTEM (EVAP. CS)	14	14	14	14
TESTING OR INSPECTION[1][3]	7	7	7	7
TOTAL	124	219	159	144
HC/CO RELATED	85	180	120	105
NO_x RELATED	39	39	39	39

[1] 1/3 COST ALLOCATED TO EACH CONSTITUENT (HC, CO, NO_x)
[2] COST ALLOCATED TO NO_x CONTROL ONLY
[3] MAY OR MAY NOT BE REQUIRED; COSTS MAY BE DIFFERENT THAN THOSE ASSUMED

a delta cost average of $2800 for the diesel engine plus HDV vehicle modifications incorporated in typical diesel-powered HDVs.

Finally, a delta cost of $2500 was selected as a "representative" value for the diesel-powered HDV. As noted, the only emission control device considered for the diesel engine was EGR, at a $30 initial cost (same as gasoline engine EGR cost).

The HDV fuel costs used are summarized in Table 5-4 for both cases. The 5.0 mpg fuel economy was selected for the 454-CID gasoline engine based on extrapolations of the fuel economy characteristics of Figure 2-3 (Section 2.2) and Figure 2.11 of Ref. 5-2 (a correlation of 350- and 450-CID fuel economies up to I_W values of 10,000 lb). The diesel

Table 5-2. Maintenance Costs -- Gasoline HDV; 454-CID Engine (12. 6 years and 130, 000 mi)

MAINTENANCE ASSUMPTIONS, $/mi	COMPONENT	CALSPAN No.			
		2	3	6	8
-60/50,000(1)	EI	-156	-156	-156	-156
NONE REQ'D	QHI				
15/50,000	IC	39	39	39	
45/50,000	AC				117
4/10,000(2)	EGR	52	52	52	52
NONE REQ'D	TR				
10/25,000	AI	52	52		52
127/25,000(3)	OC		508		
5/10,000	BYPASS		65		
3/YEAR	INSPECTIONS	38	38	38	38
12.50/25,000	EVAP. CS	65	65	65	65
TOTAL		90	663	38	168
HC/CO RELATED		77	650	25	155
NO_x RELATED		13	13	13	13

(1) 1/3 OF SAVINGS ALLOCATED TO EACH CONSTITUENT (HC, CO, NO_x)

(2) COST ALLOCATED TO NO_x CONTROL ONLY

(3) CONVERTERS CHANGED AT 25,000; 50,000; 75,000; AND 100,000 mi

baseline fuel economy of 7. 5 mpg is based on the brake specific fuel consumption values of Table 2. 21 of Ref. 5-2; they indicate the diesel mpg is approximately 1. 5 times the gasoline engine mpg value. The 4 percent fuel economy penalty shown for the diesel engine EGR case is again based on values reported in Ref. 5-2.

The only diesel engine maintenance cost considered is that associated with EGR maintenance. Based on the same assumptions used for gasoline engine EGR maintenance, Table 5-5 shows a lifetime maintenance cost of $190. Also shown in Table 5-5 are the total lifetime costs for the diesel engine with EGR (includes initial, maintenance, and fuel cost penalty).

Table 5-3. Diesel Engine Cost Summary -- HDV; 680-CID Engine

METHOD 1	METHOD 2	METHOD 3
\$ 800 = COST ΔOF 680-CID DIESEL OVER 680-CID GASOLINE (1) 100 = ΔOF STRUCTURE AND BRAKES 125 = ΔOF POWER STEERING 700 = ΔOF 680-CID GASOLINE OVER 454-CID GASOLINE(2) \$1725 = TOTAL ΔINITIAL COST OF DIESEL VS GASOLINE ENGINE FOR SAME TRUCK APPLICATION	IN 300 to 400 bhp RANGE: \$/hp DIESEL ~ 11 \$/hp GASOLINE ~ 3 RATIO = 3.67 454-CID GASOLINE = \$ 630 DIESEL = \$2300 ΔCOST = \$1670 FOR SAME POWER RATING (ENGINE ONLY)	LIST PRICE DIFFERENTIALS:(3) A. CHEV. GVW = 16000 lb GASOLINE = \$ 3500 DIESEL = \$ 6056 Δ = \$ 2556 B. CHEV. GVW = 23000 lb GASOLINE = \$ 8128 DIESEL = \$11126 Δ = \$ 2998 C. DIAMOND REO GVW = 42000 lb GASOLINE = \$12466 DIESEL = \$15325 Δ = \$ 2859 ΔAVG. ~ \$ 2800
ΔCOST OF \$2500 SELECTED AS "REPRESENTATIVE"		

ONLY EMISSION CONTROL DEVICE CONSIDERED IS EGR AT \$30 INITIAL COST

(1)EXTRAPOLATED FROM FIGURE 3.15, CALSPAN REPORT (Ref. 5-2)
(2)EXTRAPOLATED FROM FIGURE 3.13, CALSPAN REPORT (Ref. 5-2)
(3)BRANHAM AUTOMOBILE REFERENCE BOOK (Ref. 5-4)

The total HDV overall lifetime gasoline and diesel engine costs are summarized in Table 5-6.

5.3 BASELINE EMISSIONS

The gasoline and diesel engine baseline emissions (prior to adding specific ECSs) used for cost factor analysis are shown in Table 5-7; the HC, CO, and NO_x values were extrapolated from characteristics developed in Ref. 5-2. For comparative purposes in cost factor determination, the gasoline engine baseline emissions were used as the reference base from which to compute emission reductions over the vehicle lifetime. In this manner, the diesel engine per se can be considered as an ECS because its baseline emissions are lower than the gasoline engine baseline emissions (except for the direct injection NO_x value).

Table 5-4. Fuel Costs -- HDV (GVW = 22,600 lb; I_w = 15,000 lb)

PARAMETER	GASOLINE (454-CID engine)	DIESEL (680-CID engine)	
		BASELINE	WITH EGR
FUEL ECONOMY, mpg	5.0	7.5 (1)	7.2 (2)
GALLONS USED	26,000 (3)	63,300 (4)	66,000 (4)
FUEL COST AT 38 cents/gal	$9,900	$24,000	$25,000
FUEL PENALTY COST FOR EMISSION CONTROL DEVICE, $			
ECS No. 2 (5%)	495		
ECS No. 3 (5%)	495		
ECS No. 6 (8%)	790		
ECS No. 8 (3%)	295		
EGR (DIESEL ONLY)			1000

(1) BASED ON lb/bhp-hr RATIOS, TABLE 2.21, CALSPAN REPORT (Ref. 5-2)

(2) 4% FUEL PENALTY FOR EGR

(3) OVER 130,000 mi

(4) OVER 475,000 mi

5.4 COST FACTOR COMPARISONS

The resultant HDV cost factors are shown in Figures 5-1, 5-2, and 5-3 for HC, CO, and NO_x, respectively. In Figures 5-1 and 5-2, the diesel values are entered at their baseline emission rates since no additional HC or CO control devices other than the diesel engine *per se* are involved. The resultant positive-valued cost factors shown are based on the delta cost of the diesel engine being an emission control cost. However, if the inherent fuel savings of the diesel engine (over the gasoline engine) are included in the cost factor equation, the diesel cost factors become negative as compared with the gasoline engine used as the baseline for comparison.

As shown in Figure 5-3, other anomalies result in the case of NO_x control. Here, the diesel points shown are entered at their NO_x

Table 5-5. Maintenance Costs -- Diesel HDV
(12.6 years and 475,000 mi)

AT \$4/10,000 mi = 4 x 47.5 = \$190.00 OVER LIFETIME

TOTAL LIFETIME Δ COSTS - - DIESEL

BASELINE (NO EGR) - -	**\$2500**
WITH EGR	
•INITIAL 2500 + 30 FOR EGR	**2530**
•MAINTENANCE	**190**
• Δ FUEL COST	**1000**
TOTAL	**\$3720**

emission rate with EGR added to the diesel engine (see Table 5-7 for nonEGR rates of 25 gm/mi for direct injection and 10 gm/mi for prechamber diesel). The nonprimed values shown for the diesel are based on the reductions from the gasoline engine baseline NO_x emission rate. This results in a very high NO_x cost factor (greater than \$800/ton) for the direct injection diesel with EGR, since its baseline emissions were very high (25 gm/mi). The prechamber diesel with EGR has a much lower cost factor (\$210/ton) because of its lower baseline NO_x emission rate (10 gm/mi). If the diesel NO_x cost factors are based on reductions from diesel engine baseline values, the direct injection cost factor is greatly reduced (approximately \$200/ton) and the prechamber cost factor is greatly increased (approximately \$540/ton).

Table 5-6. Cost Summary -- HDV (GVW = 22, 600 lb; I_w = 15, 000 lb)

COST CATEGORY	GASOLINE (454-CID engine)				DIESEL (680-CID engine)	
	CALSPAN No.					
	2	3	6	8	BASELINE	EGR
OVERALL SYSTEM						
INITIAL COST	124	219	159	144	2500	2530
MAINTENANCE COST	90	663	38	168		190
Δ FUEL COST (1)	495	495	790	295		1000
TOTAL	709	1377	987	607	2500	3720
HC/CO RELATED						
INITIAL COST	85	180	120	105	2500	2500
MAINTENANCE	77	650	25	155		
ΔFUEL COST (1)	0	0	0	0		
TOTAL	162	830	145	260	2500	2500
NO_x RELATED						
INITIAL COST	39	39	39	39		30
MAINTENANCE	13	13	13	13		190
Δ FUEL COST (1)	495	495	790	295		1000
TOTAL	547	547	842	347	0	1220

(1) ALL GASOLINE ENGINE Δ FUEL COSTS ALLOCATED TO NO_x CONTROL

It is apparent, therefore, that comparing diesel and gasoline engine cost factors using one or the other as a baseline for comparison can be much like comparing apples and oranges unless the basis for comparison and the assumptions made in the comparison are constantly held in mind and considered in the interpretive answer.

Because of this inherent difficulty, one further comparison parameter -- the cost factor index -- was developed. It combines total fuel costs over the vehicle life (Table 5-4) with the total ECS related costs developed earlier (Table 5-6). A summary is given in Table 5-8 of the resulting total lifetime costs, lifetime emission reductions (from gasoline engine baseline values), and cost factor index values. The cost factor index values are

Table 5-7. Baseline Emissions for Cost Factor Comparisons -- HDV

ENGINE	EMISSIONS, gm/mi		
	HC	CO	NO_x
GASOLINE(1)	10.2	126.0	17.0
DIESEL(2)			
• DIRECT INJECTION	3.6	13.5	25.0
• PRECHAMBER	0.35	6.0	10.0

(1) EXTRAPOLATED FROM CALSPAN MDV REPORT, FIGURES 2.7, 2.8, AND 2.9 (Ref. 5-2)

(2) EXTRAPOLATED FROM CALSPAN MDV REPORT, FIGURE 2.18 (Ref. 5-2)

graphically displayed in Figure 5-4. Although not a true cost factor comparison, the cost factor index comparison clearly illustrates that the diesel engine with EGR can produce lower emission rates (HC + CO or HC + CO + NO_x) at lower overall costs per ton of pollutant removed than a gasoline HDV engine with an oxidation catalyst plus EGR (ECS No. 3), if the inherent fuel economy advantage of the diesel engine is given full consideration.

5.5 COST FACTOR SUMMARY

As previously discussed, it is very difficult to compare gasoline and diesel powered HDVs on a simple cost factor basis because of their

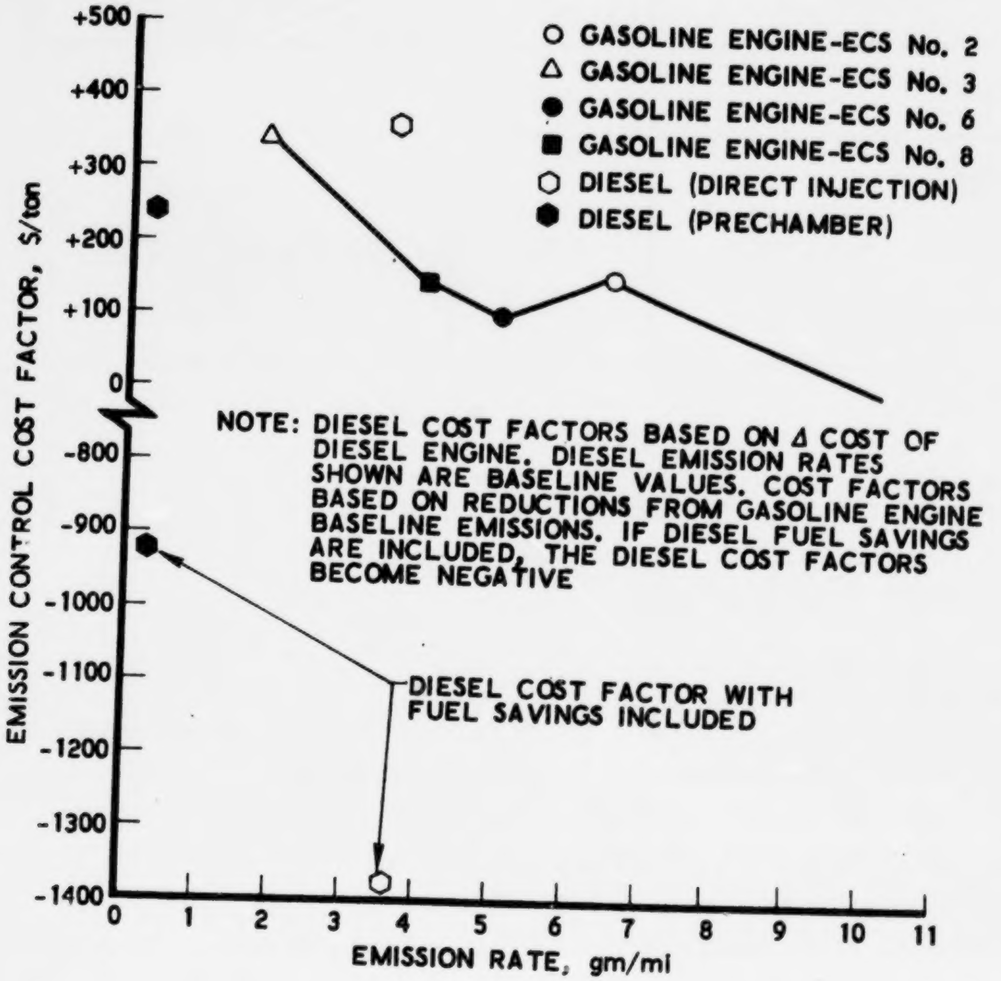

Figure 5-1. The HC Cost Factor Comparison -- HDV (GVW = 22, 600 lb; I_w = 15, 000 lb)

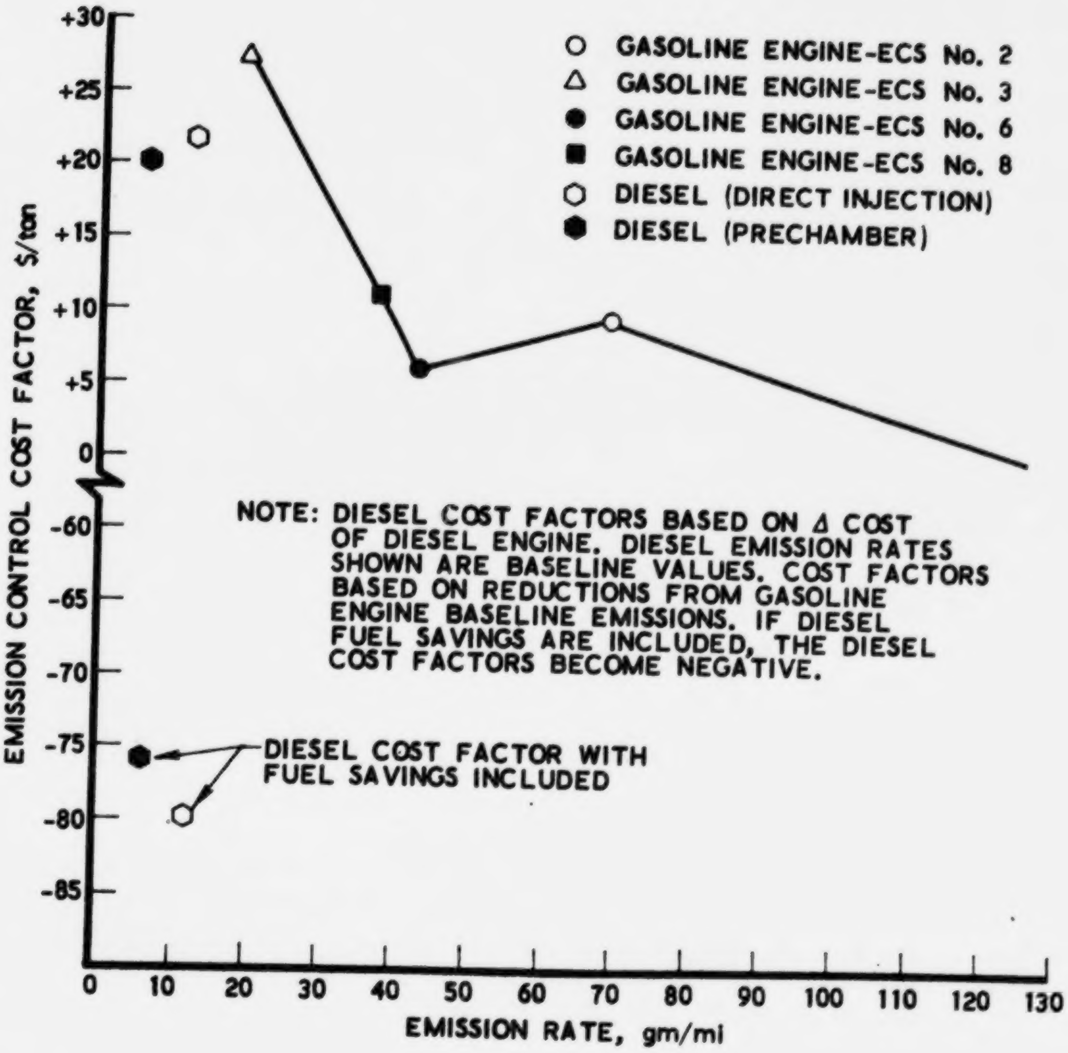

Figure 5-2. The CO Cost Factor Comparison -- HDV (GVW = 22,600 lb; I_w = 15,000 lb)

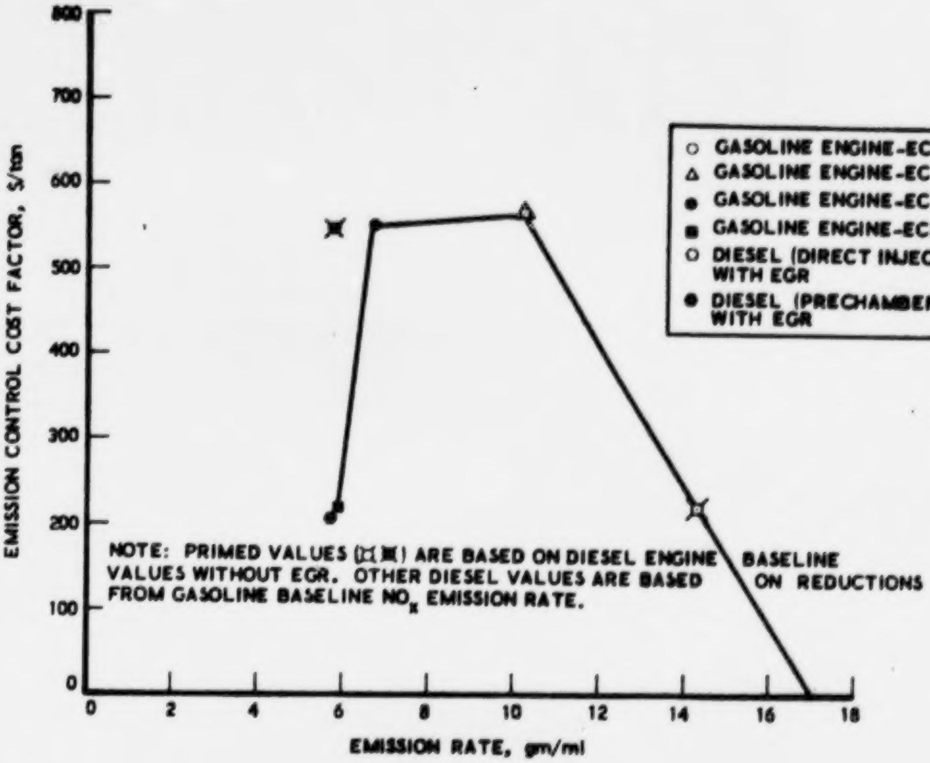

Figure 5-3. The NO_x Cost Factor Comparison -- HDV (GVW = 22,600 lb; L_w = 15,000 lb)

inherently different fuel economy characteristics. However, the following significant points are made:

a. If the diesel engine inherent fuel economy advantage is included, diesel cost factors for HC and CO are negative when compared with positive cost factors for gasoline engines.

b. If the diesel engine fuel economy advantage is not considered, diesel HC and CO cost factors are somewhat comparable to a gasoline engine with oxidation catalyst and EGR (ECS No. 3) cost factors.

c. With EGR, direct-injection diesel engines and gasoline engines have NO_x cost factors in the same general range. However, the prechamber diesel can be higher in NO_x cost factor because of lower uncontrolled NO_x rates.

d. The cost factor index comparison clearly illustrates the overall advantage of diesel systems in terms of combined emission reductions and total costs.

Table 5-8. Cost Summary; Cost Factor Index -- HDV (GVW = 22,000 lb; L_w = 15,000 lb)

Cost factor index combines total fuel costs with emission control device costs to portray economic impact of higher inherent fuel economy of diesel engine.

COST CATEGORY	GASOLINE (454-CID ENGINE)				DIESEL (680-CID ENGINE)			
	CALSPAN No.							
	2 IC/AI/EGR	3 OC/EGR	6 LTR	8 AC	BASELINE		EGR	
INITIAL COST, $	124	219	159	144	2500		2530	
MAINTENANCE Δ COST, $	90	663	38	168			190	
TOTAL FUEL COST, $	10,395	10,395	10,690	10,195	24,000		25,000	
TOTAL LIFETIME COSTS, $	10,609	11,277	10,887	10,507	26,500		27,720	
					(2)	(3)	(2)	(3)
TOTAL EMISSION REDUCTIONS,(1) tons (HC + CO + NO_x)	9.604	17.523	13.975	15.107	58.26	71.51	63.89	73.76
COST FACTOR INDEX $/ton	1103	642	779	696	454	370	414	359
HC PLUS CO REDUCTIONS,(1) tons	8.631	16.550	12.450	13.525	62.45	67.85	62.45	67.85
COST FACTOR INDEX, $/ton	1230	680	875	777	409	377	444	408

(1) REDUCTIONS FROM GASOLINE ENGINE BASELINE VALUES

(2) DIRECT INJECTION

(3) PRECHAMBER

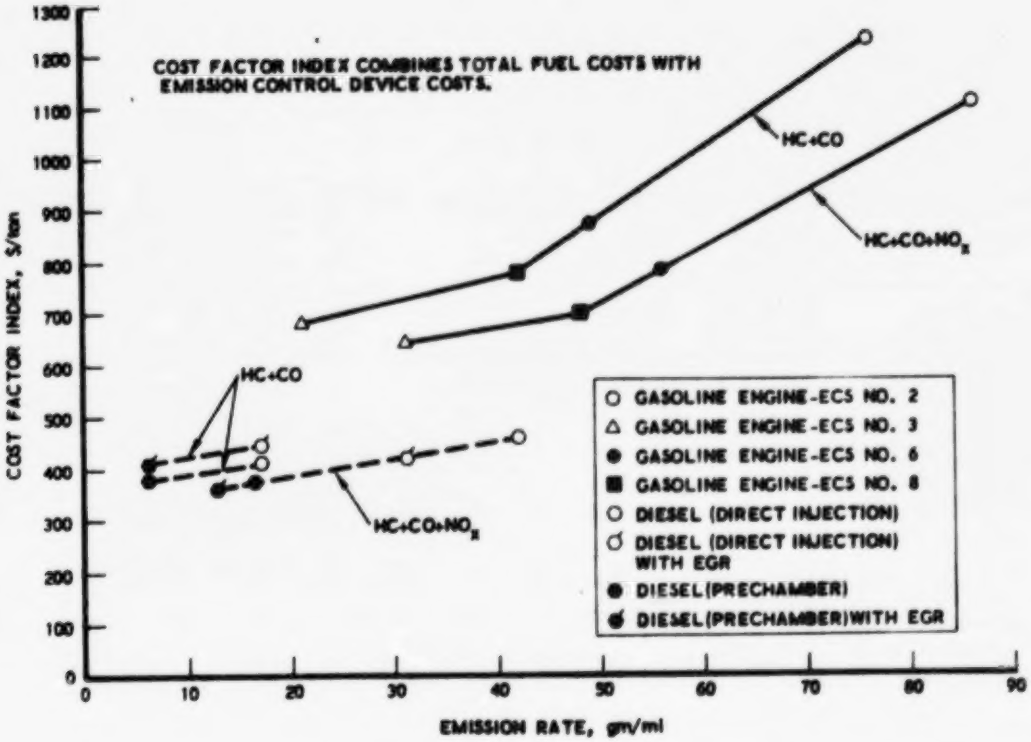

Figure 5-4. Cost Factor Index Comparison -- HDV
(GVW = 22,600; L_w = 15,000 lb)

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SECTION 6

STATIONARY SOURCE EMISSION CONTROL COSTS

This section presents emission control cost factors ($/ton pollutant reduced) for several categories of stationary sources for comparison with mobile cost estimates. Several combustion modification approaches to NO_x reduction in utility steam boilers received major attention since this is an important source of the pollutant and considerable cost/operating data were available in the literature. In addition, cost factors are included for the following sources: (a) nitric acid plant (NO_x), (b) refinery cracking unit (CO), (c) bulk gasoline loading (HC), (d) service station tank filling (HC), (e) automobile refueling (HC), and (f) petroleum storage tanks (HC).

As with most cost data, disagreements are to be expected among authorities, especially when general or "average" figures are quoted or when sufficient actual operating data have not yet been accumulated. With this caveat, the data presented below are intended to illustrate the wide range of stationary sources emission control costs that have been reported and some trends with plant size or amount of pollutant being controlled. For each example, data references are provided to enable the reader to investigate in greater depth the source and assumptions behind the cost figures.

6.1 CONTROL OF NO_x FROM UTILITY STEAM BOILERS

6.1.1 The NO_x Control Costs for Utility Steam Boilers

The most comprehensive study to date on NO_x control costs for large utility steam boilers was conducted by Esso Research and Engineering Company (Ref. 6-1). An assessment of available and potential control technology was made on the basis of cost effectiveness. Technically attractive combustion modification techniques included: low excess air firing, two-stage combustion, flue gas recirculation, steam or water injection, and combinations of techniques. Data for various types and sizes of power boilers in several sections of the country were used to select a set of 15 "composite" boilers to represent all United States boilers operating in the year 1980. These boilers had average net 1000, 750, 500, 250, and 120 MW capacities and burned gas, oil, and coal. The assumed breakdown of the number and sizes of these boilers by fuel used is shown in Table 6-1.

Control costs for a 250 MW boiler are shown in Table 6-2; similar data are presented for the other four boiler sizes in Ref. 6-1. Low excess air firing can result in a net saving due to increased boiler efficiency; in general, this is the cheapest combustion control method (Ref. 6-2).

To obtain an indication of the effect of boiler size on control costs, the data in Ref. 6-1 were cross-plotted in Figures 6-1 and 6-2 for gas- and oil-fired boilers, respectively. Three control methods are shown to illustrate the trend of higher cost factors associated with the smaller boilers. This results from a number of factors: (a) engineering costs are not very dependent on size, (b) smaller units are less flexible and require more upgrading than larger units, (c) material and fabrication costs are not proportional to size (Ref. 6-2).

Table 6-1. Fossil Fuel Boilers -- 1980
(Ref. 6-1)

CAPACITY RANGE, MW	AVERAGE NET GENERATING CAPACITY	NUMBER OF BOILERS BY FUEL			
		GAS	OIL	COAL	TOTAL
LESS THAN 200	120	155	71	474	700
200 TO 400	250	40	18	122	180
400 TO 600	500	27	12	81	120
600 TO 800	750	23	11	71	105
800 AND OVER	1000	20	9	61	90
TOTALS		265	121	809	1195

Table 6-2. Control Costs of NO_x for Utility Steam Boiler--
250 MW Boiler at 3942 hr/year (Ref. 6-1)

Control Method	% NO_x Reduction	Fuel Used	Cost Per Year \$1000	NO_x Reduction, 1000's of tons/yr	Control Costs, \$/ton NO_x
Uncontrolled (Base Case)	0	Gas	0	2.44 (2)	0
	0	Oil	0	4.83 (2)	0
	0	Coal	0	4.88 (2)	0
1. Low Excess Air (1)	33	Gas	-4	0.81	-5
	30	Oil	-44	1.5	-29
	25	Coal	0	1.2	0
2. Two Stage Combustion	45	Gas	52	1.1	47
	35	Oil	52	2.2	24
	30	Coal	103	1.5	69
3. Low Excess Air Plus Two-Stage Combustion	60	Gas	49	1.5	33
	55	Oil	9	2.9	3
	50	Coal	104	2.4	43
4. Flue Gas Recirculation	30	Gas	58	0.73	80
	30	Oil	58	1.5	39
	30	Coal	58	1.5	39
5. Low Excess Air Plus Flue Gas Recirculation	60	Gas	55	1.5	37
	55	Oil	15	2.7	6
	50	Coal	59	2.4	24
6. Water Injection	10	Gas	29	0.24	121
	10	Oil	36	0.49	74
	10	Coal	29	0.49	59

(1) INCLUDES 1% REDUCTION IN GAS FUEL, 2% REDUCTION IN OIL FUEL, 1.5% REDUCTION IN COAL FUEL DUE TO HIGHER EFFICIENCY

(2) 1000's OF TONS OF NO_x EMITTED FROM AN UNCONTROLLED BOILER

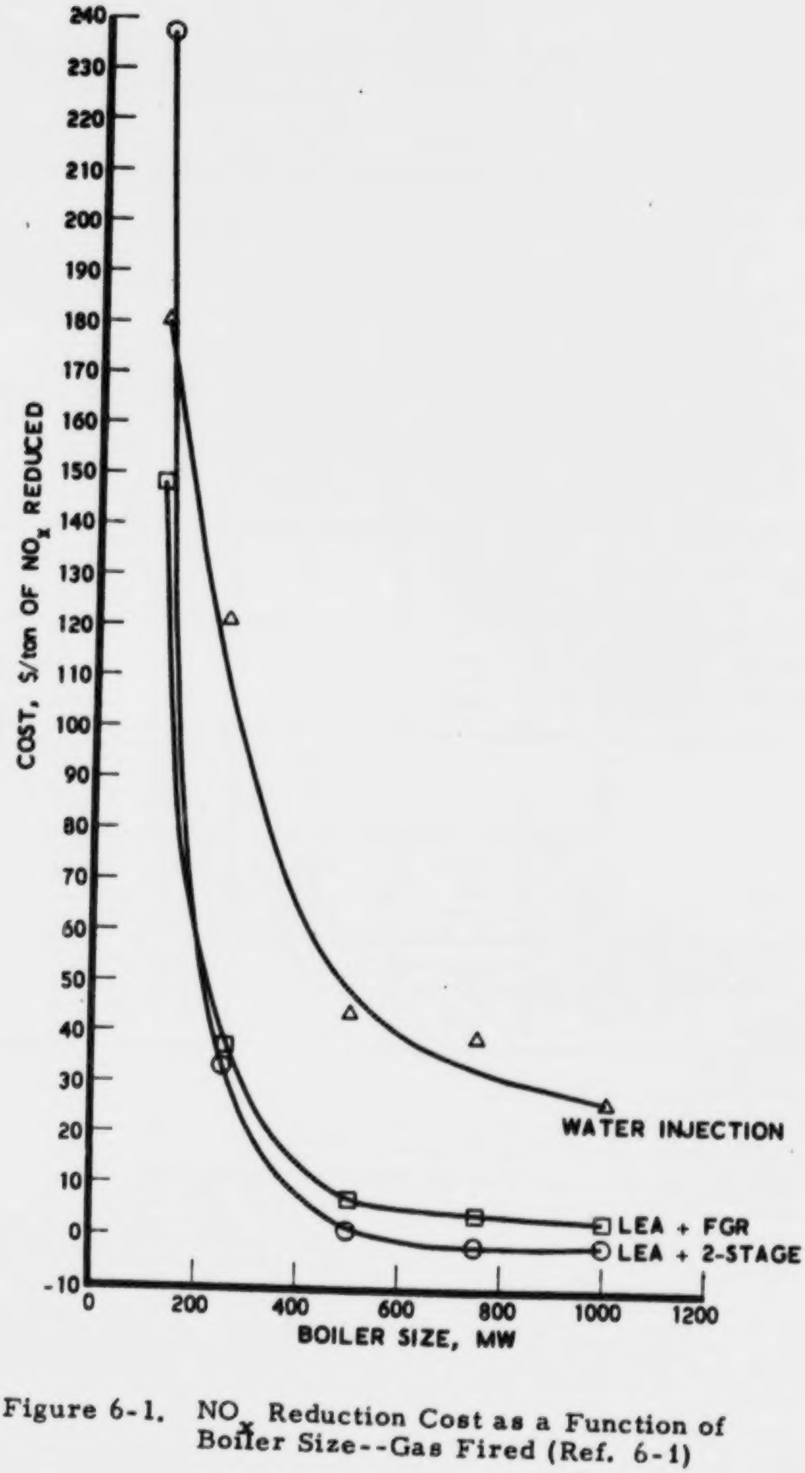


Figure 6-1. NO_x Reduction Cost as a Function of Boiler Size--Gas Fired (Ref. 6-1)

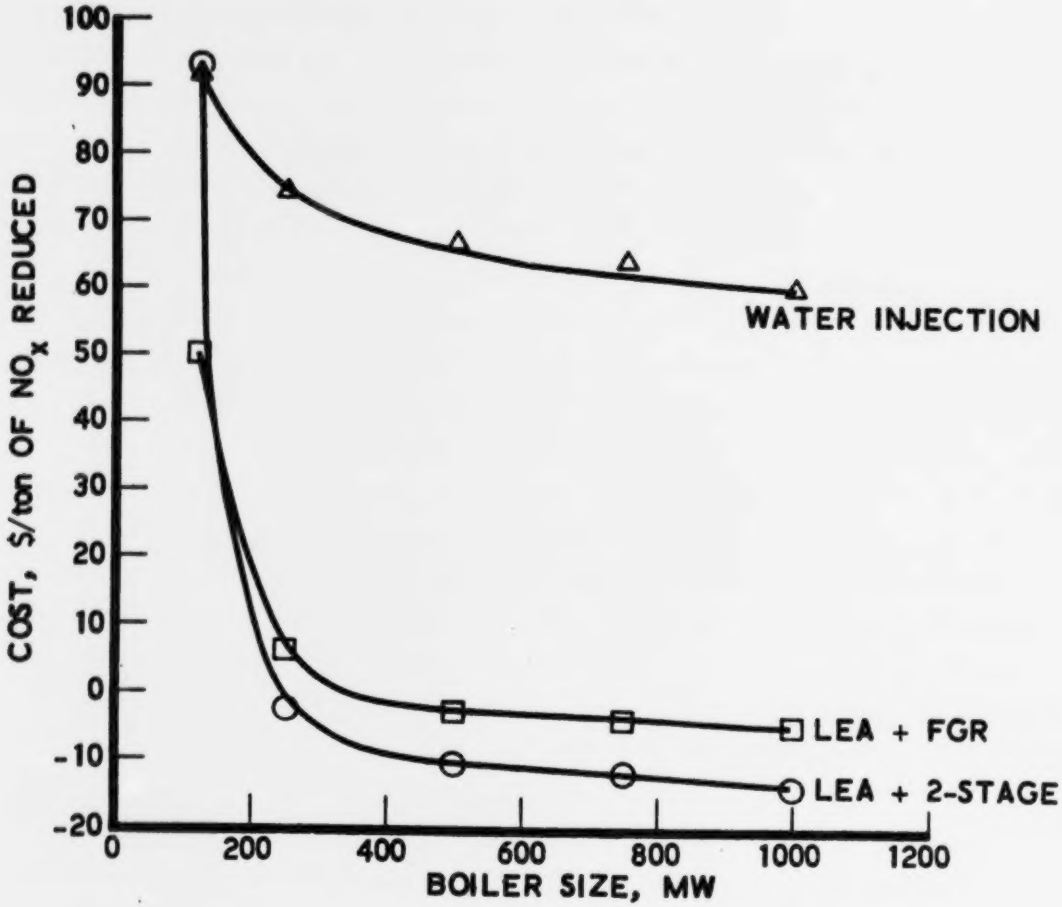


Figure 6-2. NO_x Reduction Cost as a Function of Boiler Size--Oil Fired (Ref. 6-1)

Water injection is significantly more expensive than the other approaches because of boiler efficiency losses (1 to 6 percent reported) and the resulting increased fuel usage. Esso (Ref. 6-1) assumed that water injection would be economically unfeasible if injected in quantities sufficient to cause losses in efficiency greater than 1 percent. At this injection rate, it estimated that a 10 percent reduction in NO_x emissions would result.

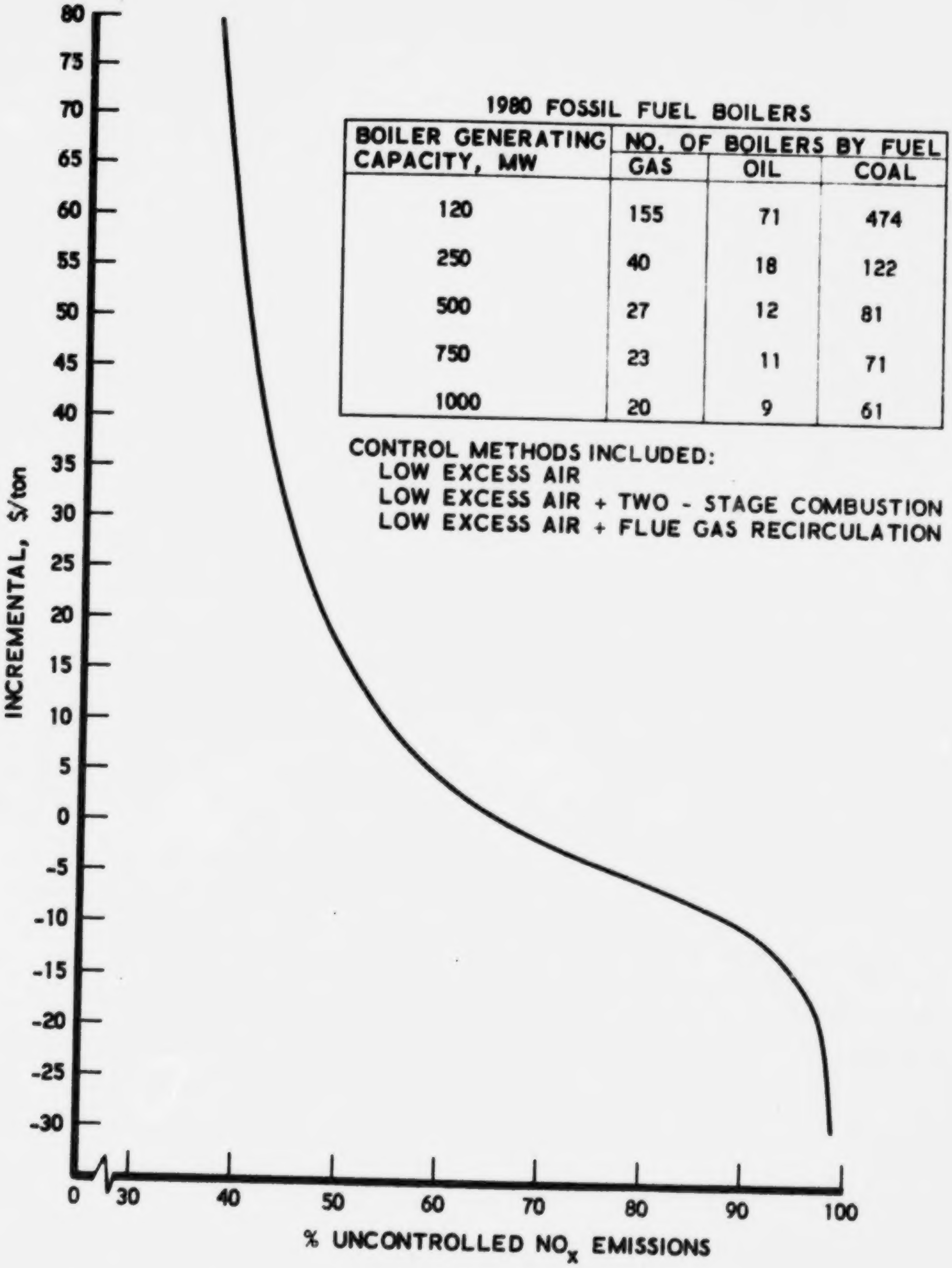
Using their estimated 1980 inventory of composite boilers and NO_x cost factors, Esso developed a minimum cost path for achieving increasing levels of NO_x removal. With some mathematical manipulation of the data, it was shown (Figures 6-3 and 6-4) that the cost for NO_x abatement increases as the total NO_x emissions are reduced to lower and lower levels. Figure 6-3 depicts this effect in terms of incremental cost (i. e., the dollars per ton of NO_x removed at each point in the reduction sequence). Only the three most cost-effective combustion control methods were used in constructing the curve. Initial NO_x reductions (right end of curve) are achieved primarily by low excess air firing with a net cost saving due to increased efficiency, as previously discussed. As the degree of NO_x control increases, the less cost-effective approaches must be involved. After approximately a 35 percent removal of the NO_x, all methods that provide cost savings have been used and further efforts must incur cost penalties.

The same basic data were also plotted in Figure 6-4 to show the average cost per ton of NO_x removed in reaching a specific level of control. The general shape of the curve is the same as in Figure 6-3, and the same message is evident. It becomes more and more expensive to remove the NO_x as the amount of NO_x remaining is reduced.

Although specific values of cost or control effectiveness in the Esso report (Ref. 6-1) may be argumentative, it does represent a comprehensive and integrated study with results that indicate the relative cost effectiveness of various NO_x abatement approaches and the magnitude of the cost factors involved.

6. 1. 2 Implementation Time for NO_x Control Systems

The preceding discussion has focused on the cost aspects of NO_x control in utility steam boilers in line with the general theme of the study. However, interest was expressed by EPA personnel in the time involved in implementing these control techniques. Such information is not readily available; it has not been included in most reports and publications covering the

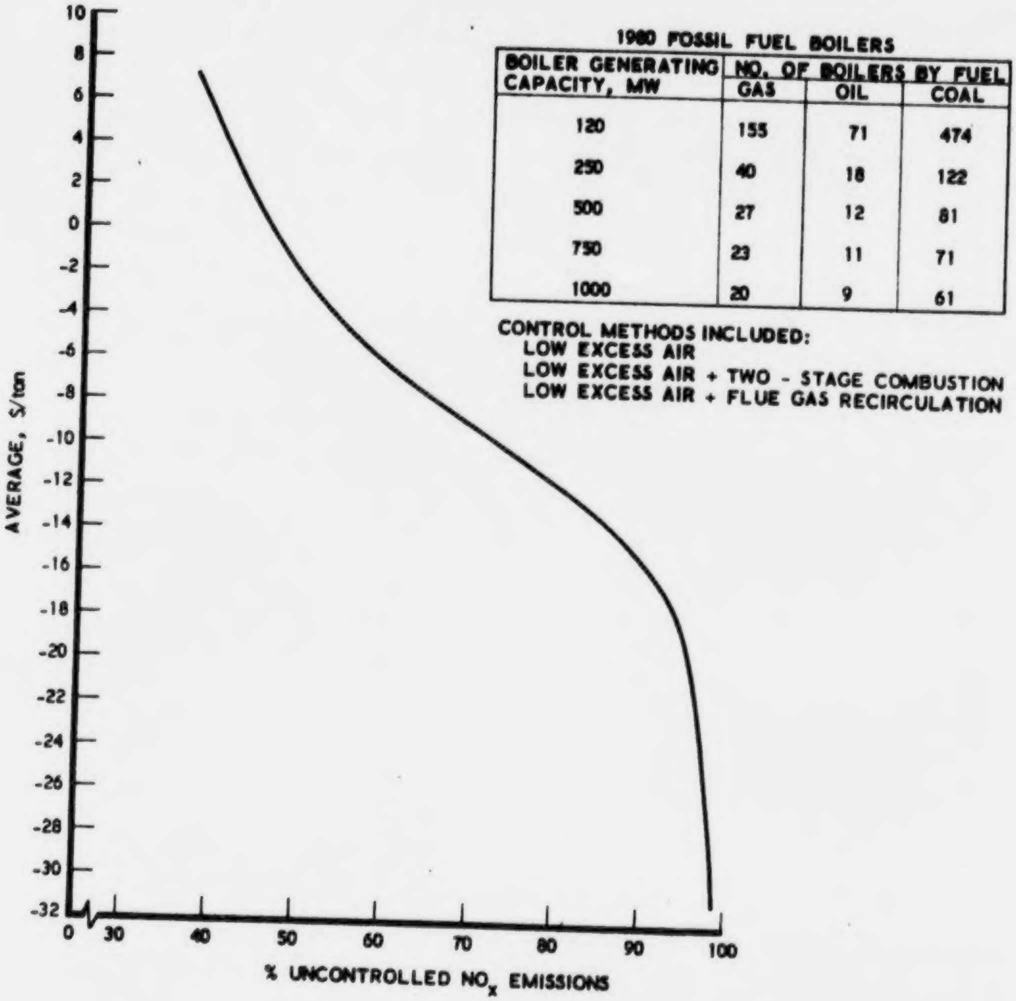


1980 FOSSIL FUEL BOILERS

BOILER GENERATING CAPACITY, MW	NO. OF BOILERS BY FUEL		
	GAS	OIL	COAL
120	155	71	474
250	40	18	122
500	27	12	81
750	23	11	71
1000	20	9	61

CONTROL METHODS INCLUDED:
- LOW EXCESS AIR
- LOW EXCESS AIR + TWO - STAGE COMBUSTION
- LOW EXCESS AIR + FLUE GAS RECIRCULATION

Figure 6-3. Incremental Cost Per Ton for NO$_x$ Abatement -- 1980 U. S. Power Boilers; Minimum Cost Control Approach (Ref. 6-1)



1980 FOSSIL FUEL BOILERS

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CONTROL METHODS INCLUDED:
LOW EXCESS AIR
LOW EXCESS AIR + TWO - STAGE COMBUSTION
LOW EXCESS AIR + FLUE GAS RECIRCULATION

Figure 6-4. Average Cost Per Ton for NO_x Abatement -- 1980 U. S. Power Boilers; Minimum Cost Control Approach (Ref. 6-1)

technical and economic factors in boiler emission reduction. Fortunately, some pertinent data were obtained from personal discussions with utility companies (Ref. 6-3 and 6-4), and are presented below.

Almost all power boilers operating in the United States are custom-made (Ref. 6-1) to specifications resulting from a complex set of interacting construction and operating cost variables (e. g. , unit capacity, fuel type and quality, and type of firing). The difficulty and time involved in modifications for reduced emissions (and the cost-effectiveness of such modifications) are significantly affected by the particular boiler design, operation, and auxiliary equipment. The following implementation data are connected with specific installations and can be expected to vary at other facilities.

To set the modification times in proper perspective, the total period for addition of a new boiler is approximately 6-1/2 years (Ref. 6-3). This encompasses all activities from preliminary engineering through preparation of specifications, contract award, site preparation and construction, and startup to commercial operation. This time is representative of a large, modern boiler plant (Scattergood 3) that includes flue gas recirculation and two-stage combustion with tangential burners.

Two examples of retrofit operations were obtained from Ref. 6-3. One was a conversion to low excess air firing. This is a modification of operating conditions requiring primarily installation of sensitive CO instrumentation. A little less than 1 year was required -- preparation of specifications (2 months), advertising and award of contract (3 months), delivery of instrumentation (4 months), installation and checkout (1-1/2 months). For conversion to two-stage operation, approximately 1-1/2 years were required, from initiation of design to checkout and testing of final operating conditions. These times do not include feasibility demonstration nor technique development, but started with a good knowledge of the design requirements.

A further example was obtained from Ref. 6-4. Four 80-MW boilers were modified with a flue gas recirculation (FGR) system for NO_x reduction; they were already equipped with simple FGR for temperature control, but required extensive duct rework and equipment additions. From go-ahead in July 1971 to initiation of system testing took about 1-3/4 years. At this point, it was found that the flame detector system necessary for automatic operation was inadequate and a newly developed scanner had to be ordered with a 6-month delivery time. It is now forecast that the units will be on automatic operation with FGR by October 1974, a total period of 3-1/3 years. While awaiting delivery and installation of the flame detector equipment, the boilers have been operating without the new FGR system.

6.2 OTHER STATIONARY SOURCE COST FACTORS

An effort was made to determine cost data for emission control in other industries and operations to supplement that found for utility boiler plants. Interest centered on those pollutants of prime importance from mobile sources; (viz., NO_x, CO, and HC) so that cost comparisons could be made. Relatively little information was found that allowed calculation of cost factors on the basis of dollars per ton of pollutant removed; in addition, there were conflicting cost estimates by different investigators. The following sections present six of these emission control cost studies covering NO_x, CO, and HC pollutants.

6.2.1 Control of NO_x from Nitric Acid Plants

The tail gas from the NO_2-water absorption tower in the nitric acid production process typically contains 0.3 to 0.5 percent NO_2 and NO. These compounds can be reduced to acceptable levels by reaction with hydrocarbon or hydrogen fuel over a catalyst. It is estimated that by 1977 applying catalytic reduction technology could reduce expected emissions by 89 percent -- 229,500 tons/year reduced to 25,000 tons/year. Annual expenditures would be $14 million for a cost factor of $69/ton of NO_x removed ($14 million divided by 204,500 tons). Costs include a high-temperature combustor, waste heat boiler, catalyst, piping, and instrumentation. No credit was included for the steam generated.

6.2.2 Control of CO from Refinery Cracking Units

In petroleum processing, cracking units employ catalysts in the form of solid beads, pellets, and powders that become coated with carbon from coking reactions of the feed materials. To maintain catalyst activity, these carbon deposits must be periodically burned off the catalyst surface at a controlled temperature, leading to the formation of CO in the regenerator. There is also a small amount of hydrocarbons in the exit gas (approximately 1.6 percent of the CO weight).

The CO waste heat boiler affords a means of using the heat of CO (and hydrocarbons) combustion and the sensible heat of the regeneration gases. The boiler is similar in design to a utility plant unit with water-cooled walls and tangential burners. In most cases, supplementary fuel is required to ensure stable operation (Ref. 6-5). Control is considered to be 100 percent.

Cost factors for CO abatement from this source were derived in two ways with reasonably good agreement. The Los Angeles Air Pollution Control District (LAAPCD) quoted an investment cost of $1.5 million to eliminate 250 tons/day of CO in a new facility (Ref. 6-6). The relationship given in Ref. 6-7 for calculating annual cost from investment cost for this type of unit was then applied

$$A = 0.2 \times 0.5 \times I$$

where

A = annual cost, dollars

0.2 = depreciation and other capital charges of 20 percent per annum

0.5 = portion of installed cost chargeable to pollution control, allowing for steam generated

I = installed cost, dollars

From this equation, the annual cost is $150,000 and the cost per ton of CO reduced is $1.67/ton.

To verify this factor, the data in Ref. 6-7 were employed in two calculations. If a catalyst regenerator capacity of 120,000 bbl/day is assumed, fifty percent of the installed cost of a CO boiler is $900,000 (Figure 4-5 of Ref. 6-7), and the associated annual cost is $180,000. If an uncontrolled CO emission factor of 5.6 tons of CO per 1000 bbl of feed for fluid catalytic crackers and 1.2 tons of CO per 1000 bbl for Thermofor units is used, the cost per ton of CO removed ranges between $0.74 and $3.47, which brackets the previously calculated value.

Another approach was to use the total pollution control cost and emissions for the entire refinery industry, as presented in Ref. 6-7. A figure of $73.3 million annual control cost is given, covering five control systems. The fraction of this cost attributable to CO boilers is not given, but it apparently will lie between one-eighth and one-fourth, based upon sample cost breakdowns presented for a large and small producer, respectively. The amount of CO controlled is given as 12.1 million tons/year. Thus, the cost factor per ton lies between $0.76 and $1.52, which is a reasonable check considering the assumptions made.

6.2.3 Control of HC in Bulk Gasoline Loading

An estimate was made of the cost to control HC vapor emissions during gasoline truck or tank car loading at bulk facilities using data in Ref. 6-8. An investment of $3 million by the petroleum industry is given for Los Angeles County to reduce HC emissions from transfer operations by more than 90 percent. This amounts to 50 tons/day or one-third of total facility emissions. Based upon a 20 percent annual charge, a cost of $0.6 million, and 18,000 tons/year reduction, the cost factor is $33/ton of HC reduced. No allowance was made for the value of recovered products.

A partial confirmation of this figure was obtained from Ref. 6-6. The investment cost for a vapor return system at the loading facility was given as $54,000/ton of HC controlled per day. With a 20 percent annual cost as before, the cost factor comes to $30/ton of HC reduced. Although the ultimate source of all these data was the LAAPCD, the fact that the data were quoted in different terms and at widely different times gives some justification for assuming a degree of independence and confirmation.

6.2.4 Control of HC in Service Station Tank Filling Operations

The next step in gasoline marketing is the transfer to underground tanks at the retail service station. Cost data for control of HC emissions during tank filling operations in Los Angeles County have been recently published (Ref. 6-9). Submerged fill pipes have been already installed as a result of a 1964 rule. The new requirement involves at least 90 percent recovery of the displaced vapors by return lines to the delivery truck. The rule requires that tanks of 6000 gallons capacity or greater be modified by 1 May 1975, and tanks less than 6000 gallons by 1 May 1976. Existing tanks smaller than 2000 gallons are exempt.

The quoted investment cost for all the tanks (25,268) falling under the rule is $6.3 million for tank modifications and $0.75 million for tank truck alterations. The reduction in HC is estimated to be 33 tons/day. Thus, the cost factor is $119/ton of HC controlled ($7.05 million × 0.2/ 33 × 360).

6.2.5 Control of HC in Automobile Refueling

The last step in gasoline marketing is filling the automobile tank. Various control systems are feasible, including simple displacement, absorption, adsorption, refrigeration, liquefication, and thermal oxidation. Equipment incorporating one or several of these methods is being built and installed in San Diego County to meet requirements for at least 90 percent HC control (Ref. 6-10).

Costs are given as $200 to $480/ton of HC reduced (Ref. 6-10); savings from the recovered product are not included.

Other studies have arrived at somewhat higher costs. Thus, Ref. 6-11 gives a range of $260 to $1080/ton of HC reduced, based upon data in the APIEF-14 Phase I Interim Report by Refinery Management Services Company, dated April 1973, and data from the CAPE-9 Project of the Coordinating Research Council. In Ref. 6-12, a cost range of $470 to $1410/ton is estimated. Some cost elements given in Section 6. 2. 4 may be included in these costs, since systems to recover hydrocarbons from auto refueling usually include equipment to return vapors to tank trucks during bulk filling.

6. 2. 6 Control of HC from Petroleum Storage Tanks

Breathing and filling losses from large petroleum refinery storage tanks can be an important source of HC emissions. One technique for eliminating such losses is to install floating roof tanks, as described in Ref. 6-7. It is estimated in this reference that, on a nationwide basis, the installation of floating roof tanks would cost $79. 74 million and reduce HC emissions by 1. 053 million tons/year in FY 1977 (89 percent control). On the basis of 20 percent annual depreciation and capital charges, the cost factor is approximately $15/ton of HC controlled. The value of the recovered vapors has not been included; it should more than offset any operating and maintenance costs.

6. 3 SUMMARY

These data are summarized in Table 6-3 for the various stationary sources. The cost factors range from a savings for low excess air firing of utility boilers to expenses as high as $1400/ton for automobile refilling operations. For NO_x control, a maximum value of $69/ton is shown for a nitric acid plant; however, this cost can be exceeded somewhat for small size (less than 250 MW) utility boilers and/or by use of the more expensive control techniques.

Control of HC appears to rise as the amount of petroleum/gasoline being controlled decreases. This is evident by examining the

Table 6-3. Summary of Emission Control Costs for Stationary Sources

EMISSION SOURCE	CONTROL TECHNIQUE		CONTROL EFFECTIVENESS, % REDUCTION	COST, $/ton OF POLLUTANT		
				NO_x	CO	HC
UTILITY BOILERS (250 MW unit)	LEA	GAS	33	-5		
		OIL	30	-29		
		COAL	25	0		
	LEA + TWO STAGE	GAS	60	33		
		OIL	55	3		
		COAL	50	43		
	LEA + FGR	GAS	60	37		
		OIL	55	6		
		COAL	50	24		
NITRIC ACID PLANT	CAT-REDUCTION OF TAIL GAS		89	69		
REFINERY CRACKING UNIT	CO BOILER		100		1.67	
PETROLEUM STORAGE TANKS	FLOATING ROOF		89			15
GASOLINE BULK LOADING	VAPOR RECOVERY		>90			33
SERVICE STATION TANK FILLING	VAPOR RECOVERY		>90			119
SERVICE STATION AUTO FILLING	VAPOR RECOVERY		>90			200 to 1400

gasoline marketing sequence: storage tanks ($15/ton), bulk loading ($33/ton), service station filling ($119/ton), and automobile filling ($200 to 1400/ton).

Control costs for CO are very low for the one example considered. Since CO is usually controlled to low levels in stationary sources by good design and operating practices, it is difficult to find many examples of specific control systems.

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6-3. Personal communication from R. Toda, Los Angeles Department of Water and Power.

6-4. Personal communication from C. Giles, Southern California Edison Company.

6-5. Control Techniques for Carbon Monoxide Emissions from Stationary Sources, Publication AP-65, National Air Pollution Control Administration (March 1970).

6-6. Personal communication from Los Angeles Air Pollution Control District.

6-7. D. A. Le Sourd and F. L. Bungard, eds., Comprehensive Study of Specified Air Pollution Sources to Assess the Economic Impact of Air Quality Standards, Report FR-41U-649 Research Triangle Institute (August 1972) [Contract 68-02-0088 (EPA)].

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6-10. B. R. McEntire and R. Skoff, "Hydrocarbon Vapor Control at Gasoline Service Stations," Paper No. 73-333 presented at the June APCA meeting.

6-11. Personal communication from R. E. Maxwell, Office of Air and Water Programs, Environmental Protection Agency.

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SECTION 7

MOBILE AND STATIONARY SOURCE COST FACTOR SUMMARY

Representative emission control cost factors developed for LDVs and MDVs (Section 4. 1), HDVs (Section 5), and various stationary sources (Section 6) are summarized here to permit an overview comparison and to draw conclusions as to meaningful trends.

Mobile and stationary source emission control cost factors are listed by emission constituent in Table 7-1 to facilitate the comparison. The cost factors for LDVs and MDVs are those derived from 1972 LDV technology emission baseline assumptions. The ranges of mobile source cost factor values shown, as noted in the table, encompass the spectrum of emission control devices considered: ECS No. 2 through No. 8 for LDVs and MDVs; ECS No. 2, 3, 6, and 8 for gasoline-powered HDVs; and EGR for diesel-powered HDVs. However, for each LDV, MDV, and gasoline-powered HDV case, the cost factor based on ECS No. 3 (1975-type passenger car oxidation catalyst plus EGR) is shown in parentheses for a common baseline of comparison.

As discussed in Section 5, two types of cost factors are shown in Table 7-1 for diesel-powered HDV HC and CO control. The positive-valued cost factors are computed without regard to the diesel's fuel economy advantage; the negative-valued cost factors are the result of including diesel fuel cost advantages in the cost factor equation.

Table 7-1. Summary of Emission Control Cost Factors

EMISSION SOURCE		COST FACTORS, $/ton REMOVED(1)		
		HC	CO	NO_x
MOBILE SOURCES	LIGHT DUTY VEHICLES (4500 lb inertia test weight)	550 to 1800(2) (1800)(3)	60 to 180(2) (180)(3)	500 to 2300(2) (1200)(3)
	MEDIUM DUTY VEHICLES 6000 lb INERTIA TEST WEIGHT	400 to 1650(2) (1650)(3)	40 to 140(2) (140)(3)	500 to 2600(2) (1280)(3)
	9000 lb INERTIA TEST WEIGHT	280 to 850(2) (850)(3)	18 to 60(2) (60)(3)	500 to 2800(2) (1350)(3)
	HEAVY DUTY VEHICLES (15,000 lb test weight) GASOLINE-POWERED	100 to 350(2) (350)(3)	6 to 27(2) (27)(3)	200 to 550(2) (550)(3)
	DIESEL-POWERED	240 to 360(4) -921 to -1375(5)	20 to 21(4) -76 to -80(5)	200 to 850
STATIONARY SOURCES	UTILITY BOILERS (250 MW) LEA	--	--	0 to -29(6)
	LEA + TWO STAGE	--	--	3 to 43(6)
	LEA + FGR	--	--	6 to 35(6)
	NITRIC ACID PLANT (catalyst reduction)	--	--	69
	REFINERY CRACKING UNIT (CO boiler)	--	1.67	--
	PETROLEUM STORAGE TANKS (floating roof)	15	--	--
	GASOLINE BULK LOADING (vapor recovery)	33	--	--
	SERVICE STATION--TANK FILLING (vapor recovery)	119	--	--
	SERVICE STATION--AUTO FILLING (vapor recovery)	200 to 1400	--	--

(1) THE VALUES SHOWN IN THIS TABLE ARE BASED ON A NUMBER OF ASSUMPTIONS AND LIMITATIONS AS INDICATED IN THE TEXT OF THE REPORT

(2) FUNCTION OF SPECIFIC EMISSION CONTROL SYSTEM EMPLOYED

(3) VALUES IN PARENTHESES ARE FOR 1975-TYPE CATALYST CONTROL SYSTEM

(4) FUEL ECONOMY IMPROVEMENT OVER GASOLINE ENGINE NOT INCLUDED

(5) FUEL ECONOMY IMPROVEMENT OVER GASOLINE ENGINE ALLOCATED TO HC AND CO CONTROL

(6) VARIES WITH FUEL TYPE (gas, oil, coal)

7.1 MOBILE SOURCE COST FACTOR COMPARISONS

Comparison of the mobile source cost factors in Table 7-1 suggests the following overview remarks:

a. Control of HC -- These cost factors decrease as the vehicle loaded weight increases, for the same ECS type. In this regard, MDV HC control can be termed more "cost-effective" than LDV HC control, and similarly, that HDV HC control is more cost-effective than MDV HC control. It is observed that diesel-powered HDVs can have negative cost factors if the diesel inherent fuel advantage over the gasoline engine is accredited proportionally to HC and CO control.

b. Control of CO -- These cost factors are an order of magnitude lower than HC cost factors. This is a direct result of their relative baseline emission levels. These cost factors also decrease with increasing vehicle loaded weight. Thus, HDV and MDV control is more cost-effective than LDV control. Diesel-powered HDVs can also have negative CO cost factors.

c. Control of NO_x -- These cost factors vary across the vehicle loaded weight spectrum due to the variation in fuel economy and L_w relationship. With the 1972 LDV engine technology baseline for comparison, as shown in Table 7-1, the MDV has NO_x cost factors slightly above LDV cost factors. However, with the "earlier" technology emission baseline for comparison (Section 4.1), the MDV has lower NO_x cost factors than the LDV. The diesel-powered HDV NO_x cost factors are in the same general range as gasoline-powered HDV NO_x cost factors.

7.2 MEDIUM-DUTY VEHICLE AND STATIONARY SOURCE COST FACTOR COMPARISONS

Comparison of the MDV cost factors in Table 7-1 with those for stationary sources suggests the following overview remarks. However, it should be noted that many stationary sources were not examined; therefore, these comments may not apply across the board to other systems.

a. Control of HC -- The MDV HC cost factors can be orders of magnitude higher than HC control from some stationary sources (e.g., petroleum storage tanks, gasoline bulk loading, and service station tank filling). However, control of HC during automobile refueling operations at the service station can result in a cost factor in the same range as MDV values.

b. Control of CO -- The MDV CO cost factors can also be orders of magnitude higher than cost factors for CO control in a refinery cracking unit (CO boiler).

c. Control of NO_x -- The MDV NO_x cost factors can be considerably higher than stationary source NO_x control; however, the absolute comparison values depend on the source compared to:

   1. The MDV NO_x cost factor range is from \$500 to 2800/ton.
   2. The 250 MW utility boiler NO_x cost factor range is from -\$29 to 4[illegible]/ton.
   3. The nitric acid plant NO_x cost factor value is approximately \$69/ton.

In addition, as discussed in Section 6, the NO_x cost factors for NO_x control from utility boilers vary with power plant size. As shown in Figures 6-1 and 6-2, the NO_x cost factors for small utility boilers are considerably higher than the value shown in Table 7-1 for the 250 MW size.

SECTION 8

VEHICLE LOCATION AND TRAVEL CHARACTERISTICS

This section addresses a variety of vehicle population and travel characteristics that relate to the effectivity, desirability, and/or feasibility of controlling MDVs. The discussion is organized in three parts. Section 8. 1 presents the results and supporting analysis of an initial estimation of truck population and travel characteristics based on a consensus of various surveys, samples, and studies conducted in the three AQCRs of interest. [Phoenix-Tucson AQCR, the California South Coast Air Basin (SCAB), and various portions of the New York City area]. Section 8. 2 reexamines the travel parameters developed in Section 8. 1 and provides another quantification of truck population and travel by GVW breakdown based upon recent R. L. Polk Company registration survey counts in the three AQCRs. The two estimates given in Sections 8. 1 and 8. 2 are compared in Section 8. 3, and an evaluation is made of the relative accuracy of each estimate.

8. 1 VEHICLE TRANSPORTATION AND PLANNING STUDY RESULTS

This section presents the results and supporting analysis of an initial estimation of MDV registration and travel in three metropolitan areas: the Phoenix-Tucson AQCR, the California SCAB, and various portions of the New York City area. The study results are summarized in Table 8-1. Table 8-1 includes estimates of population and automobiles (obtained from Refs. 8-1 and 8-2, respectively) and provides comparative data for the total United States. These results are based on a variety of regional transportation surveys and studies and should be evaluated in parallel with data presented in Sections 8. 2 and 8. 3 that were developed from recent R. L. Polk Company registration survey information.

Table 8-1. Preliminary Vehicle Registration and VMT Summary -- 1970

This table is based on a number of transportation and planning studies. A final estimate of these values is given in Table 8-12.

PARAMETER	PHOENIX-TUCSON AQCR	SOUTH COAST AIR BASIN (Los Angeles)	NEW YORK CITY AREA					UNITED STATES	
			TRI-STATE (NY AQCR)	NINE COUNTIES	NEW YORK CITY	MANHATTAN	DOWNTOWN MANHATTAN	TOTAL	URBAN
POPULATION	1,429,000	9,700,000	18,700,000	11,560,000	7,890,000	1,590,000		203,000,000	
VEHICLES	821,000	5,600,000	7,300,000	3,659,000	1,762,000	231,000		101,800,000	
PERCENT AUTOS	87.0	86.7	89.5	89.5	89.0	76.0		82.0	
PERCENT TRUCKS	13.0	13.3	8.5	6.9	6.7	15.1		18.4	13.0
0 TO 6000 lb	57.6	63.3	(Same as nine counties)	49.5	72.5	(Same as New York City)	(Same as New York City)	58.5	
6000 TO 14,000 lb	31.6	27.2		21.6	6.4			19.2	
14,000⁺ lb	10.8	9.5		28.9	21.1			22.3	
TOTAL DAILY VMT	17,000,000	150,000,000	182,000,000	99,000,000	34,146,000	6,035,000			
PERCENT VMT TRUCKS	17.3	13.5	16.7		10.2	17.3(8.8 to 29.0)	42.0	19.3	15.7
0 TO 6000 lb	(Same as distribution)	(Same as distribution)	(Same as distribution)	(Same as distribution)	72.5	(Same as New York City)	(Same as New York City)		
6000 TO 14,000 lb					5.5				
14,000⁺ lb					22.0				
VMT/VEHICLE	20.7	26.8	25.0	27.3	19.3	26.1			
VMT/TRUCK	27.3	27.3	49.0		29.5	(Same as New York City)		31.6	31.3
PERCENT VMT									
LDV	92.7	95 TO 91	91.6		97.2	95.2(95.7 to 94.6)	88.5		
MDV	5.5	3.7 TO 7.7	3.6		0.5 TO 0.6	1.0(0.5 to 1.6)	2.3		
HDV	1.8	1.3	4.8		2.3	3.8	9.2		

The results summarized in Table 8-1 indicate the following:

a. The distribution of trucks by GVW and the contribution of MDVs to total vehicle miles traveled (VMT) differs in the geographical areas considered.

b. The VMT contribution of MDVs does not exceed 8 percent in any of the three areas. This result occurs because where the fraction of VMT provided by trucks was large, the fraction of trucks in the MDV class was small. Even if the largest VMT fraction were combined with the largest MDV truck fraction, the results would only produce a VMT contribution of 13 percent.

c. The percent by number and VMT contribution of HDVs in the New York City area is several times greater than corresponding values for the Phoenix-Tucson AQCR or the California SCAB.

8.1.1 Phoenix-Tucson AQCR

No direct data were available on the number or distribution by GVW of trucks in this AQCR for any recent year. The available sources consisted of a 1957 transportation survey in Phoenix (Ref. 8-3) and a detailed transportation analysis of Tucson covering the years 1960 to 1980 (Ref. 8-4). The Phoenix data showed that in 1957, 15.3 percent of the vehicles in that area were trucks, while the Tucson data showed that 13 percent of the vehicles in 1970 were expected to be trucks. Since the differences between Phoenix 1957 and Tucson 1970 were small and could possibly be explained by the time difference, the Tucson ratio (13 percent) of trucks to vehicles was used for this AQCR.

The distribution of trucks by GVW was obtained from a roadside survey of two locations within the Phoenix metropolitan area that was conducted by the Arizona Department of Highways in 1970 (Ref. 8-5). This survey indicated the distribution by truck characteristic shown in the second column of Table 8-2. It was assumed that all single-unit, two-axle trucks were MDVs (6,000 to 14,000-lb GVW). The distribution by GVW of the pickups was not specified; therefore, it was estimated (based on pickup truck sales data of Ref. 8-6) that 25 percent of the pickup trucks were also in the 6,000 to 14,000-lb GVW class. This GVW distribution of trucks is shown in the last column of Table 8-2 and was used for this AQCR in Table 8-1.

Estimates of total daily VMT were obtained separately for Phoenix (Ref. 8-7) and Tucson (Ref. 8-8) and were summed to give the total VMT for that AQCR. The fraction of the total VMT provided by trucks was assumed to be identical to that of the Phoenix area -- 17.3 percent (Ref. 8-7). This area has most of the population and vehicles in the AQCR and the truck

Table 8-2. Phoenix Truck Distribution (Ref. 8-3)

TYPE	PERCENTAGE OF TOTAL NUMBER OF TRUCKS	GROSS VEHICLE WEIGHT CLASS, lb	PERCENTAGE OF TRUCKS IN GROSS VEHICLE WEIGHT CLASS
PICKUP	77	0 TO 6,000 (75%)(1)	57.6
		6,000 TO 14,000 (25%)(1)	31.6
SINGLE UNIT, TWO AXLE	12.2	6,000 TO 14,000(2)	
OTHER	10.8	14,000^{+}	10.8

(1) BASED ON SALES

(2) ASSUMED

VMT in Tucson was not too different from Phoenix (13 percent, from Ref. 8-8).

No data were available on truck VMT by GVW; it was assumed that the distribution of truck VMT by GVW was identical to the estimate of distribution by GVW. On this basis, the percentage of total VMT provided by each truck GVW class may be obtained from the product of the percentage VMT provided by all trucks and the fraction of trucks in the GVW weight class of interest. For MDVs, for example, the product is 17.3 x 0.316 or 5.5 percent.

8.1.2 California SCAB

A preliminary study of HDV operations in the SCAB was completed by Wilbur Smith and Associates (Ref. 8-9). This study, while not directly usable, estimated the number of trucks in the region, and indicated that the distribution of trucks by weight in the SCAB would agree with the statewide distribution of trucks by weight.

Trucks in California are registered by empty vehicle weight (EVW). By using registration data (Ref. 8-10) and deleting buses, taxis, and ambulances, a distribution of trucks by EVW can be obtained. The problem is to relate EVW and GVW to determine what percentage of trucks are in the GVW classes of interest. Wilbur Smith and Associates (Ref. 8-11) were unsuccessful in developing such a correlation. It was decided, therefore, to use a correlation between "curb weight" (i. e., EVW plus the driver weight) and GVW obtained from several truck emission studies. This correlation is shown in Figure 8-1. Then it was assumed that the curb weight was equal to the EVW and that in the first approximation an EVW range of 4000 to 8000 lb is applicable to the 6,000 to 14,000-lb GVW range. This assumption was combined with the registration information given in Ref. 8-10, and Table 8-3 was developed showing the truck distribution by weight for California and the SCAB.

Population (Ref. 8-1), automobile (Ref. 8-2), truck (Ref. 8-9), and total VMT (Refs. 8-12 and 8-13) data for the region were obtained directly from the sources indicated. The vehicle total was assumed to be the sum of automobiles and trucks. As a check on the number of trucks and total VMT, a comparison was made with data derived from the Los Angeles Regional Transportation Study (LARTS) (Ref. 8-14). While the SCAB is somewhat larger than the LARTS region, the 1970 estimates of trucks and total VMT in the SCAB are somewhat lower than would be expected from the LARTS data.

8.1.3 New York Area

Five geographical regions in the New York area are represented in Table 8-1: New York City (the five boroughs); Manhattan; selected areas within Manhattan; New York City and Nassau, Rockland, Suffolk, and Westchester counties -- the "Nine County Area"; and the Tri-State Region, which includes counties in New York, New Jersey, and Connecticut and is almost identical to the AQCR.

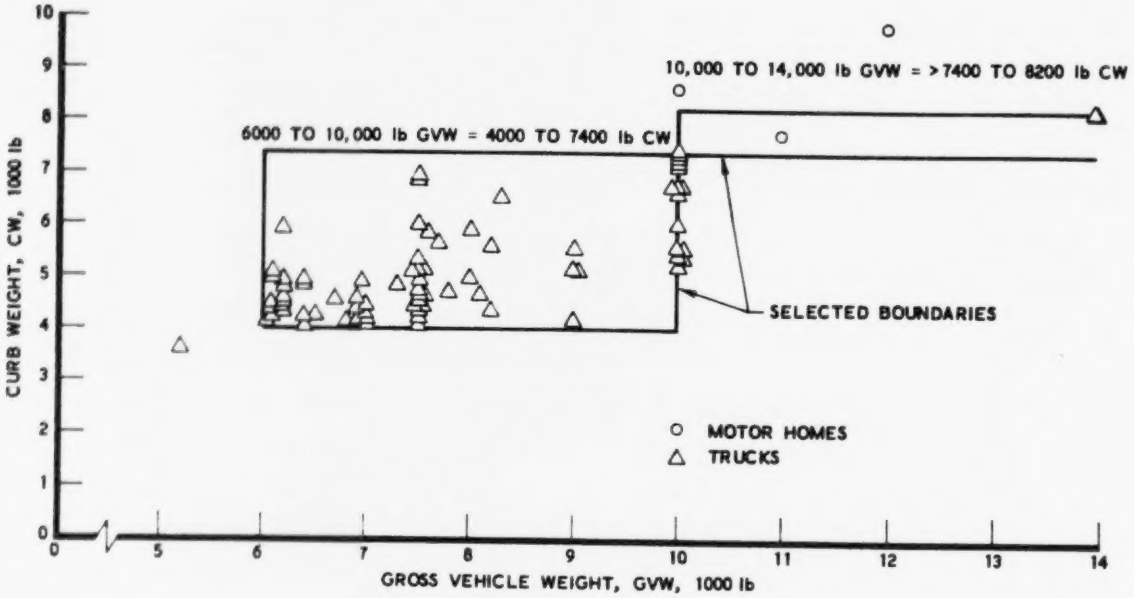

Figure 8-1. Variation of Curb Weight with Gross Vehicle Weight (Data from Appendix B)

Table 8-3. Truck Distribution by Weight in California and South Coast Air Basin

EMPTY VEHICLE WEIGHT, lb	GROSS VEHICLE WEIGHT, lb	PERCENT OF TOTAL
0 TO 4,000	0 TO 6,000	63.3
4,000 TO 8,000	6,000 TO 14,000	27.2
8,000 +(1)	14,000+	9.5

(1) MOTOR HOMES CAN HAVE AN EVW OF > 8,000 lb AND A GVW OF 10,000 TO 14,000 lb

8.1.3.1 New York City

The total VMT in New York City was taken directly from Refs. 8-15 and 8-16, population was taken from Ref. 8-1, and automobile and total vehicle population data were obtained from Ref. 8-17.

In developing the information for truck registration and distribution by GVW, it became evident that the data from different sources or within individual sources were conflicting or inconsistent; therefore, it was necessary in several instances to rely upon a best deductive judgment in making the final selection of an appropriate statistic. For example, estimating the number of trucks in New York City was confused by the lack of correlation between yearly data given in Ref. 8-17 for "commercial vehicles" and yearly truck registration data given in Ref. 8-11 (Table 2-1, loc. cit.). It was decided to use the values listed in Ref. 8-17, since the data were developed by the local transportation authority, the Tri-State Transportation Agency. Therefore, the total number of trucks in New York City in 1970 was taken to be 118,233.

The distribution of trucks by GVW was estimated by comparing two different data sets. One was a distribution for trucks greater than 6000-lb GVW, which was based on a survey conducted by the Tri-State Transportation Commission in 1963. The other encompassed all trucks and was based on 1971 motor vehicle registrations in New York City. Both distributions were provided in Ref. 8-11 (Tables 3-5, 3-6, loc. cit.). If it is assumed that the 1963 distribution holds for the year 1970, then a GVW breakdown for the categories of interest may be developed from these two data sets (Table 8-4). Note that there is an incompatibility between the numbers shown for the two data sets, particularly for the heavier trucks. For example, each set shows about the same percentage of trucks in the 19,500 to 26,000-lb GVW range, which is clearly impossible in view of the difference in the data bases. Since the desired GVW boundaries (0-6,000; 6,000 to 14,000; greater than 14,000) were not ascertainable in either single data set, the data were used for estimation purposes as follows. First, the percent distribution for the 10,000 to 19,500-lb GVW class was selected to be

Table 8-4. Truck Distribution by Weight in New York City

GROSS VEHICLE WEIGHT, lb	DATA SET 1 PERCENTAGE OF ALL TRUCKS(1)	DATA SET 2 PERCENTAGE OF TRUCKS OVER 6,000 lb(2)		COMPUTED PERCENTAGE OF ALL TRUCKS
0 TO 6,000	62.4	N. A.		72.5
6,000 TO 10,000		5.7		6.4
10,000 TO 14,000	14.8	17.5	53.8	
14,000 TO 16,000		10.4		21.1
16,000 TO 19,500		25.9		
19,500 TO 26,000	13.2	12.7		
26,000 TO 33,000	9.6	10.6		
33,000⁺		17.2		

PERCENTAGE OF TRUCKS OVER 6,000 lb $= \frac{14.8}{53.8} \times 100 = 27.5$

PERCENTAGE OF TRUCKS LESS THAN 6,000 lb = 72.5

PERCENTAGE OF TRUCKS 6,000 TO 14,000 lb $= (5.7 + 17.5)0.275 = 6.4$

PERCENTAGE OF TRUCKS 14,000⁺ lb $= 100-(72.5 + 6.4) = 21.1$

(1) Ref. 8-11, TABLE 3-6

(2) Ref. 8-11, TABLE 3-4

the broadest area of comparative commonality between the two data sets, since the higher GVW data would clearly not correlate. Since data set 2 did not consider the 0 to 6000-lb GVW class and data set 1 did, it was assumed, for first-order approximation purposes, that the total percent of trucks in data set 2 above 6000-lb GVW would be approximately equal to the ratio of the percentage distribution of the 10,000 to 19,500-lb GVW class in the two data sets. This resulted in a value of 27.5 percent, meaning that the trucks counted in data set 2 (trucks greater than 6000-lb GVW) represented only 27.5 percent of all the trucks, including trucks in the 0 to 6000-lb GVW class. In other words, then, 72.5 percent of all trucks, on this basis, would be in the 0 to 6000-lb GVW class. The data in data set 2 can then be used to determine the trucks in the 6,000 to 14,000-lb GVW class by adding the percentage values (5.7 and 17.5) and multiplying by 0.275, the conversion factor determined earlier to convert data set 2 data to data including trucks less than 6000-lb GVW. Finally, then, the percent trucks above 14,000-lb GVW is simply the percent trucks above 6000-lb GVW (27.5) minus the percent trucks in the 6,000 to 14,000-lb GVW class (6.4). These computations are illustrated on Table 8-4 and summarized in the last column. It should be noted that these rough approximations were not in good agreement with later acquired R. L. Polk Company registration data.

Total truck daily VMT is estimated in Ref. 8-11 by ratioing the total miles traveled by the number of trucks sampled in the 1963 Tri-State survey (1047) to the total number of trucks in New York City in 1963 (124,260). Since the trucks in the Tri-State survey sample were all greater than 6000-lb GVW, this procedure implicitly assumes that all trucks travel the same number of miles per day. Table 8-5, which is reproduced from Ref. 8-11 and is based on the same survey, shows that differences in VMT by GVW are not large. Since no data were available on daily VMT for trucks less than 6000-lb GVW, the above technique for estimating total truck VMT was adopted with a correction made for the fact that the number of trucks in 1970 was assumed to be 118,233. The total truck VMT was then 118,233 × 29.5 mi/truck, or 3,450,000 mi. To be consistent with this approach, the VMT data from Table 8-5 should be ignored and the distribution of VMT by GVW should be assumed equal to the registration distribution. For comparison purposes, however, the data of Table 8-5 were used to compute a VMT distribution by GVW. As shown in Table 8-1, the difference between these approaches is not large (0.5 percent versus 0.6 percent of total VMT for MDVs), nor is the contribution of MDVs to the total VMT significant.

Table 8-5. New York City Data -- Summary of Urban Truck Travel Characteristics by GVW Category (Ref. 8-11)

VEHICLE MILES	GROSS VEHICLE WEIGHT CATEGORY, lb						
	6,000 10,000	10,000 14,000	14,000 16,000	16,000 19,500	19,500 26,000	26,000 33,000	OVER 33,000
PERCENTAGE OF TOTAL	4.6	15.0	9.3	27.2	12.3	11.8	19.8
PERCENTAGE OF TOTAL DAILY TRUCK-TRIPS	7.0	19.0	11.9	26.3	15.0	10.2	9.8
TRUCK POPULATION PERCENTAGE OF TOTAL FROM TRI-STATE SURVEY	5.5	17.5	10.4	25.9	12.7	10.7	17.3
AVERAGE MILES PER TRIP, mi	1.62	2.18	2 14	2.85	2.26	3.20	5.56
AVERAGE MILES PER TRUCK, mi	25.1	25.4	26.8	31.2	28.8	32.8	34.1
AVERAGE TRIP SPEED, mph	7.5	8.5	8.0	9.7	8.3	6.9	10.4
AVERAGE NUMBER TRIPS PER TRUCK PER DAY	15.1	11.7	12.4	10.8	12.8	10.2	6.1

8.1.3.2 Manhattan (New York County)

Population data were obtained from Ref. 8-3; automobile, truck, and total vehicle population statistics were obtained from Ref. 8-17; and total VMT was obtained from Ref. 8-15. No data were available on the truck distribution or VMT contribution by GVW for Manhattan. It was assumed that the distribution and VMT contribution by GVW were identical to those of New York City. Since 30 percent of all New York City trucks are registered in Manhattan (Refs. 8-11 and 8-17), the total truck VMT in Manhattan was assumed to be 30 percent of the citywide estimate.

The estimated truck VMT in Manhattan can vary greatly depending upon the approach used. In Ref. 8-15, two approaches are suggested: one using truck bridge and tunnel crossings, and the other using trip destinations. The truck bridge and tunnel crossing approach assumes that the truck VMT fraction in any borough is identical to the fraction of all crossings contributed by trucks. According to crossing data provided in Ref. 8-15, only 8.8 percent of the total VMT in Manhattan was contributed by trucks. However, the concept of using crossing data to estimate truck VMT appears at variance with data provided in Ref. 8-11, which indicates that most truck trips are internal to a given borough.

The trip distribution data provided in Ref. 8-15 indicate that 29 percent of the total Manhattan VMT was contributed by trucks. It may be noted that the use of trip distribution data is supported by Ref. 8-18, which shows a correlation between trips per square mile and VMT per square mile.

The total range of MDV contribution to the total VMT by these various approaches is shown in Table 8-1 and appears to be small regardless of the approach used. The primary reason for this is that the fraction of trucks that are MDVs is small in Manhattan.

8.1.3.3 Selected Areas in Manhattan

Reference 8-15 provides data (Table 4-17, loc. cit.) that show that in certain areas of Manhattan, particularly below 14th Street, the fraction of total VMT contribution by trucks could be as high as 42 percent.

If one assumes that this area has the same distribution and VMT contribution of trucks by GVW as in Manhattan and the rest of New York City, MDVs could contribute 2.3 percent of the total local VMT, as is indicated in Table 8-1. The referenced data appear to be based on the relationship between trip destination and VMT discussed previously.

8.1.3.4 The Nine County Area

The primary purpose of considering the nine county area [the five boroughs (counties) of New York City plus Nassau, Rockland, Suffolk, and Westchester counties] was to develop truck distribution data by GVW for New York City and its suburbs. This distribution is given for trucks over 6000-lb GVW in Ref. 8-11 (Table 3-4, loc. cit.). When this information is combined with the distribution set for all trucks provided in Ref. 8-11 (Table 3-6, loc. cit.), a distribution of trucks for the area can be computed (Table 8-6). There is a large difference in truck distribution by GVW between this nine county area and the New York City area represented in Table 8-4.

No data are available on the contribution by GVW of trucks to the VMT, and it was assumed that the contribution by GVW was the same as the distribution estimate. Information on total VMT for the nine counties may be obtained from Ref. 8-16 for 1963, but no data are available on the truck VMT or the total number of vehicles or trucks in these counties in that year. However, data are available on the total number of vehicles and trucks in the nine counties in 1970 and in the total region in both 1963 and 1970 (Ref. 8-17). The VMT per vehicle shown in Table 8-1 was obtained by assuming that the ratio of total vehicles in the nine counties to the vehicles in the region would remain unchanged between 1963 and 1970. The total VMT shown in Table 8-1 was based on the 1963 VMT-per-vehicle value.

Population data for the nine county area were obtained from Ref. 8-3; automobile, truck, and total vehicle data were obtained from Ref. 8-17.

Table 8-6. Truck Distribution by Weight -- Nine County Area

GROSS VEHICLE WEIGHT, lb	DATA SET 1 PERCENTAGE OF ALL TRUCKS[1]	DATA SET 2 PERCENTAGE OF TRUCKS OVER 6,000 lb[2]	COMPUTED PERCENTAGE OF ALL TRUCKS
0 TO 6,000	69.8		49.5
6,000 TO 10,000		40.8	21.6
10,000 TO 14,000	12.0	2.1 } 23.8	
14,000 TO 16,000		10.6	28.9
16,000 TO 19,500		11.1	
19,500 TO 26,000	10.4	19.8	
26,000 TO 33,000	7.8	7.5	
33,000⁺		8.1	

PERCENTAGE OF TRUCKS OVER 6,000 lb $= \frac{12}{23.8} \times 100 = 50.5$

PERCENTAGE OF TRUCKS LESS THAN 6,000 lb = 49.5

PERCENTAGE OF TRUCKS 6,000 TO 14,000 lb = (40.8 + 2.1)0.505 = 21.6

PERCENTAGE OF TRUCKS 14,000⁺ lb = 100-(49.5 + 21.6) = 28.9

(1) Ref. 8-11, TABLE 3-6

(2) Ref. 8-11, TABLE 3-4

8.1.3.5 The Tri-State Region

No direct data are available on the distribution by GVW or the contribution of trucks by GVW to the total VMT of the Tri-State region (includes counties in New York, New Jersey, and Connecticut). The distribution of trucks by GVW was assumed to be identical to that of the nine county area and the contribution to truck VMT was assumed to be identical to the distribution by weight. The remainder of the data provided in Table 8-1 was taken from the following references: population, Ref. 8-3; total vehicles, automobiles, and trucks, Refs. 8-17 and 8-19; and total VMT, with the exception of truck VMT, Ref. 8-19. The only available data on truck VMT are for 1963 (Refs. 8-3 and 8-20); this shows that trucks provide 16.7 percent of the total VMT for an area slightly smaller than the Tri-State Region. It was assumed that the fraction of total VMT contributed by trucks was unchanged between 1963 and 1970 and was appropriate for the Tri-State Region. These assumptions lead to a relatively high value of 49 VMT per truck (Table 8-1) and to a significant increase in the fraction of total VMT provided by MDVs over other geographic segments of the New York area.

8.1.4 Nationwide Data

8.1.4.1 Registration and VMT

Nationwide data shown in Table 8-1 are taken from Refs. 8-6, 8-21, 8-22, and 8-23. The distribution of trucks by weight shown in Table 8-1 is based on 1962 to 1970 truck sales. The percentage of trucks nationally was computed using 1970 truck registration from Ref. 8-6 (18.7 million) and auto registration from Ref. 8-23 (83.1 million).

8.1.4.2 Trends in Truck Registration and Weight Distribution

Figure 8-2 compares changes in the ratio of trucks to total vehicles in the AQCRs of interest and in the United States. In general, truck growth in the United States as a whole is greater than in the AQCRs considered. There is clearly a wide variation in the rates of change between areas studied; Tucson actually indicates a decline in the proportion of vehicles that are trucks. Figure 8-2 is based on data from Refs. 8-4, 8-6, 8-12, and 8-17.

An estimate of the variation in truck weight class is shown in Figure 8-3, where sales data over the past eight years are presented. This figure shows the rapid growth of MDVs (i.e., 6,000 to 14,000-ib GVW) rising from about 18 to 24 percent of all new truck sales in five years. Shown also is the MDV fraction for the metropolitan areas studied, indicating that for the SCAB and Phoenix-Tucson areas, MDVs are over-represented in comparison

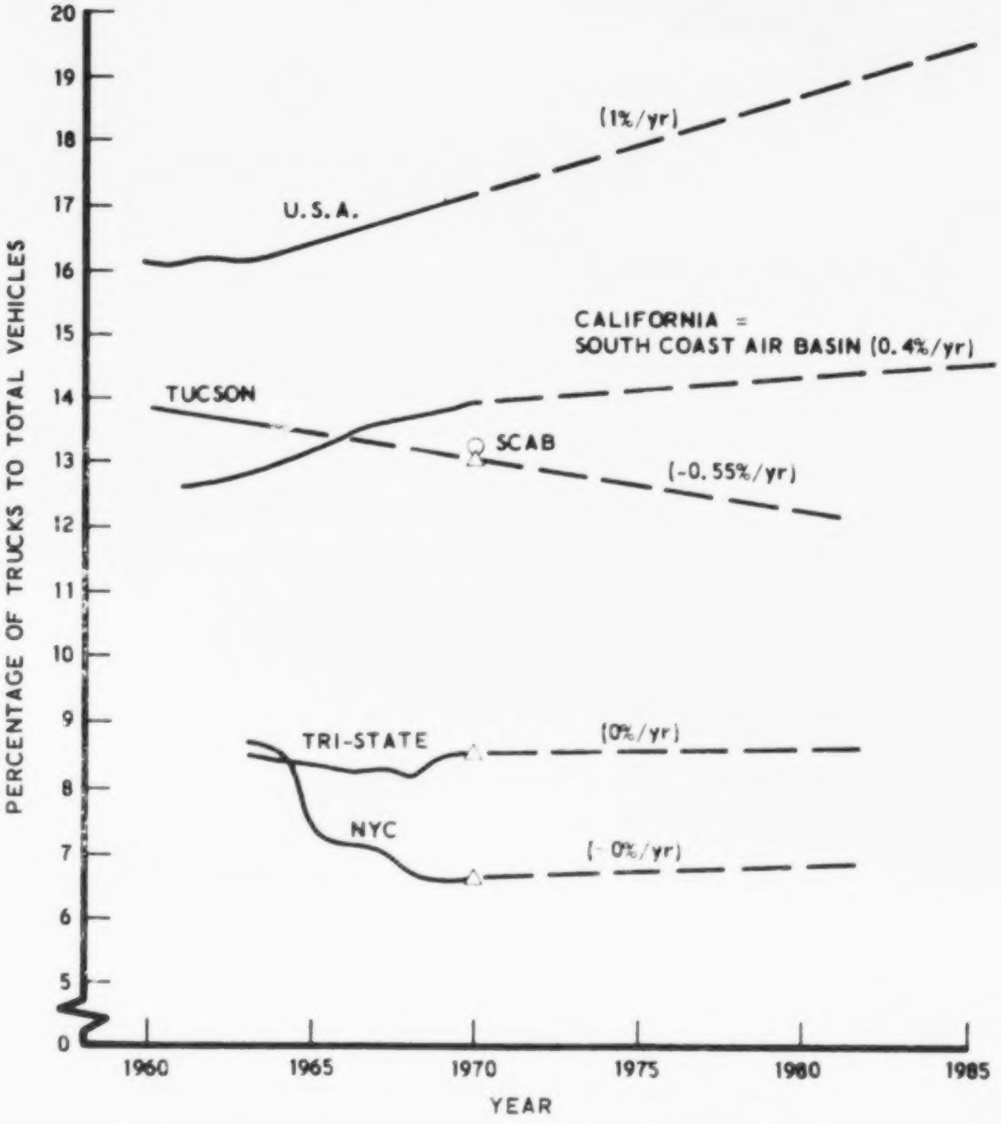

Figure 8-2. Truck Registration Percentage as a Function of Year (Refs. 8-4, 8-6, 8-12, and 8-17)

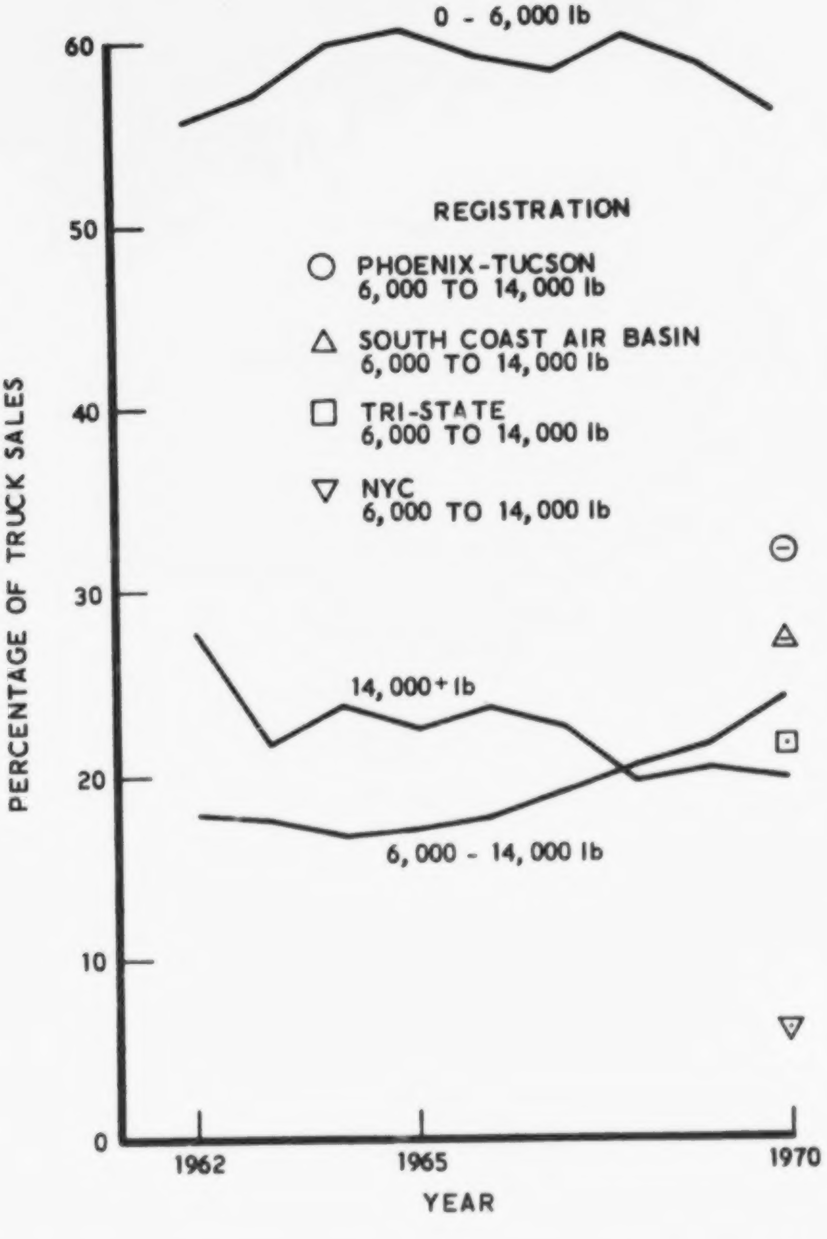

Figure 8-3. National Truck Sales Distribution by Weight Class -- 1962 to 1970 (Ref. 8-6)

to national sales data, while the New York City area is under-represented. Figure 8-3 is based on data from Ref. 8-6.

8.2 IMPACT OF VEHICLE REGISTRATION DATA ON LOCATION AND TRAVEL CHARACTERISTICS

As noted in Section 8.1, previous estimates of truck population, location, and breakdown by GVW classification have been based on a variety of survey or sampling techniques. Current estimates for the New York City AQCR, for example, are based on extrapolations of a survey made in 1963. To quantify as accurately as possible the truck population by GVW breakdown in the three AQCRs of interest (New York City, Los Angeles, Phoenix-Tucson), the R. L. Polk Company was commissioned to perform a truck registration count in these areas, with registrations separated into eight GVW groups.

8.2.1 Method of Registration Sampling

The following is a brief discussion of the procedures used to develop improved vehicle population statistics from an 80 percent registration sample taken by R. L. Polk Company. This sample, extended to 100 percent coverage, is the basis for the preparation of the July 1, 1972 Trucks in Operation statistics.

The basic R. L. Polk Company "July 1 Truck Units in Operation" report, which has been prepared by make and year model since 1933, has not been tabulated by GVW group. For the past two years, a specialized report has been compiled into four weight categories -- light, medium, heavy, and extra heavy.

This information was processed for eight GVW groups based on an 80 percent national sample using the ten most current year models. Assignment to GVW of 85 to 90 percent of the truck registration volume is based on serial number information received from the manufacturer, and 10 to 15 percent is based on the stated weight group shown on the source registration document received from the state. The accuracy of the latter group is not as high as realized through serial number data. Successful application of serial number data depends on the manufacturer's serial number patterns and keys, some are not as complete as others.

The percentage of the sample varies from state to state and county to county. The reason is that in some states the reregistration processing with each county is somewhat independent of the state. This does not cause any distortion in total; however, proportions may vary from one weight group to another.

A situation exists with mostly heavy truck registrations that should be noted. A truck may be registered in Los Angeles County because the legal owner is there; however, the truck may be traveling constantly from coast to coast and may, in fact, never enter Los Angeles County. This truck would be tabulated in the Los Angeles County statistics. There is nothing further that can be done to pinpoint these vehicles. This vehicle, because of editing procedures, will show up only once.

8.2.2 Trucks in Operation Report Results

The ten-model-year truck registration profile by GVW class, as developed by R. L. Polk Company for the county or state, as appropriate, was considered to apply equally to all model years. Applying this GVW profile (or breakdown by GVW class) to total truck registrations for the AQCRs of interest resulted in the values shown in Tables 8-7 through 8-10, for the Phoenix-Tucson, Los Angeles, and New York City AQCRs, and for New York City proper (five boroughs only).

The human and vehicle populations are summarized in each table. Passenger car and truck registrations are allocated to the county, where available. In this regard, the vehicles of the New Jersey and Connecticut portions of the New York City AQCR are based on a vehicles-per-person count with New Jersey state profiles and totals serving as the basis for projection. (The New Jersey portion in the AQCR represents approximately 70 percent of the people and vehicles in New Jersey.) The passenger car registrations shown are those from Ref. 8-23, which were also based on an R. L. Polk Company registration survey for the same areas.

Table 8-7. Total Truck Registration -- Phoenix-Tucson AQCR

State and Counties	Population	Passenger Cars Registered	Trucks Registered (by GVW Class, lb)							
			Less than 6,000	6,000 to 10,000	10,000 to 14,000	14,000 to 16,000	16,000 to 19,500	19,500 to 26,000	26,000 to 33,000	Over 33,000	Total
Arizona	1,770,990	842,893	225,656	54,203	199	1,319	4,411	9,159	1,877	5,788	302,613
LDVs		← 1,068,549 →									
MDVs				← 54,402 →							
HDVs						← 22,554 →					
AQCR	1,433,326	714,849	166,451	41,883	170	1,054	2,450	7,508	1,519	4,813	226,847
Maricopa	967,522	494,124	110,615	28,390	118	738	2,167	5,614	1,115	3,740	152,497
Gila	29,288	11,517	6,480	1,067	2	27	70	165	31	105	7,947
Pinal	67,916	24,832	9,333	1,831	7	16	136	[illegible]	47	111	12,466
Pima	354,667	177,477	37,579	10,240	43	231	[illegible]	1,402	255	809	51,110
Santa Cruz	13,966	6,905	2,064	155	[illegible]	25	32	74	18	45	2,627
Total by Class											
LDVs		← 881,300 →									
MDVs				← 42,053 →							
HDVs							← 18,344 →				

Automobiles + Trucks = 714,849 + 226,848 = 941,697

Percent Automobiles = 75.91

Percent Trucks = 24.09

Percent 0 to 6,000 lb Trucks = 17.68 (73.37 percent of all trucks)

Percent 6,000 to 14,000 lb Trucks = 4.47 (18.54 percent of all trucks)

Percent over 14,000 lb Trucks = 1.95 (8.09 percent of all trucks)

Percent Automobile VMT = 82.7 (from transportation planning studies)

Percent Truck VMT = 17.3 (from transportation planning studies)

Percent 0 to 6,000 lb Truck VMT = 12.69 (LDT VMT)

Percent 6,000 to 14,000 lb Truck VMT = 3.21 (MDV VMT)

Percent over 14,000 lb Truck VMT = 1.40 (HDV VMT)

Percent Automobile + LDT VMT = 95.39 (LDV VMT = Automobile VMT + LDT VMT)

Table 8-8. Total Truck Registration -- South Coast Air Basin AQCR

State and Counties	Population	Passenger Cars Registered	Trucks Registered (by GVW Class, lb)								
			Less than 6,000	6,000 to 10,000	10,000 to 14,000	14,000 to 16,000	16,000 to 19,500	19,500 to 26,000	26,000 to 33,000	Over 33,000	Total
California	19,953,000	9,344,450	1,408,981	549,690	2,820	17,760	31,712	86,455	20,872	54,039	2,172,329
LDVs		10,753,431									
MDVs				552,510							
HDVs						210,838					
AQCR	9,703,000	4,860,000	561,173	278,667	1,214	8,760	15,711	44,226	10,896	21,803	942,658
Los Angeles			[illegible]	174,915	820	6,318	10,872	34,611	8,625	15,783	587,793
Ventura			27,090	12,152	78	251	557	1,167	247	658	42,202
Orange			84,389	41,360	136	1,205	2,293	3,760	964	2,411	136,627
San Bernardino			52,840	[illegible]	[illegible]	477	894	2,311	536	1,438	85,413
Riverside			40,642	16,547	51	305	726	1,487	315	1,027	61,091
Santa Barbara			20,558	6,773	41	204	369	890	209	486	29,532
Total by Class											
LDVs		5,421,173									
MDVs				279,881							
HDVs						101,396					

Automobiles + Trucks = 4,860,000 + 942,658 = 5,802,658
Percent Automobiles = 83.75
Percent Trucks = 16.25
Percent 0 to 6,000 lb Trucks = 8.68 (53.55 percent of all trucks)
Percent 6,000 to 14,000 lb Trucks = 4.82 (29.69 percent of all trucks)
Percent over 14,000 lb Trucks = 1.75 (10.76 percent of all trucks)

Percent Automobile VMT = 86.5 (from transportation planning studies)
Percent Truck VMT = 13.5 (from transportation planning studies)
Percent 0 to 6,000 lb Truck VMT = 8.04 (LDT VMT)
Percent 6,000 to 14,000 lb Truck VMT = 4.00 (MDV VMT)
Percent over 14,000 lb Truck VMT = 1.46 (HDV VMT)
Percent Automobile + LDT VMT = 94.54 (LDV VMT = Automobile VMT + LDT VMT)

Table 8-9. Total Truck Registration -- Tri-State AQCR

States and Counties	Population	Passenger Cars Registered	Trucks Registered (by GVW Class, lb)								
			Less than 6,000	6,000 to 10,000	10,000 to 14,000	14,000 to 16,000	16,000 to 19,500	19,500 to 26,000	26,000 to 33,000	Over 33,000	Total
New York	18,236,967	6,224,601	373,812	163,609	2,681	25,753	28,513	62,612	24,070	29,276	710,326
New Jersey	7,168,164	3,260,464	181,540	47,781	718	7,808	10,635	31,645	17,456	21,235	318,818
Connecticut	3,031,709	1,378,000	76,726	20,194	303	3,300	4,495	13,375	7,377	8,975	134,745
Totals	28,436,840	10,863,065	632,078	231,584	3,702	36,861	43,643	107,632	48,903	59,486	1,163,889
LDVs		11,495,143									
MDVs				235,286							
HDVs						296,525					
AQCR	17,402,249	6,112,907	268,752	97,165	1,975	20,240	22,714	59,025	25,125	29,941	524,939
New York	11,571,899	3,456,907	121,094	58,302	1,391	13,890	14,064	33,286	10,927	12,669	265,623
Bronx	1,471,701	258,349	6,063	2,864	88	817	736	1,872	668	887	13,995
Kings	2,602,012	504,620	13,818	5,948	217	2,058	1,908	5,209	1,662	2,460	33,277
Nassau	1,428,080	738,148	22,229	10,700	243	2,504	2,121	6,887	2,189	2,080	48,953
New York	1,539,233	189,932	10,045	5,570	216	2,505	2,329	6,420	1,980	1,314	30,682
Queens	1,986,473	553,586	13,536	6,412	225	1,992	1,576	4,803	1,354	1,782	31,680
Richmond	295,443	114,208	3,353	1,455	31	280	209	424	185	387	6,026
Rockland	229,903	108,970	4,362	2,395	26	238	284	782	263	453	8,803
Suffolk	1,124,950	531,230	32,403	15,079	198	1,691	3,632	4,071	1,031	1,526	59,631
Westchester	894,104	421,867	15,583	7,879	147	1,502	1,272	2,818	1,595	1,780	32,576
New Jersey	5,066,180	2,310,000	128,308	33,769	507	5,518	7,516	22,365	12,337	15,008	225,328
Bergen	98,012										
Essex	929,986										
Hudson	609,266										
Middlesex	583,813										
Monmouth	459,379										
Morris	383,454										
Passaic	460,782										
Somerset	198,372										
Union	543,116										

Table 8-9. Total Truck Registration -- Tri-State AQCR (Continued)

States and Counties	Population	Passenger Cars Registered	Trucks Registered (by GVW Class, lb)								
			Less than 6,000	6,000 to 10,000	10,000 to 14,000	14,000 to 16,000	16,000 to 19,500	19,500 to 26,000	26,000 to 33,000	Over 33,000	Total
AQCR (Cont'd)											
Connecticut Portion	764,170	546,000	[illegible]	994	77	812	1,114	1,174	1,861	2,264	33,988
LDVs		[illegible],149,351									
MDVs				49,140							
HDVs						187,048					

Automobiles + Trucks = [illegible]

Percent Automobiles = 92.09

Percent Trucks = 7.91

Percent 0 to 6,000 lb Trucks = 4.05 (51.2 percent of all trucks)

Percent 6,000 to 14,000 lb Trucks = 1.49 (18.84 percent of all trucks)

Percent over 14,000 lb Trucks = 2.37 (29.96 percent of all trucks)

Percent Automobile VMT = 83.3 (from transportation planning studies)

Percent Truck VMT = 16.7 (from transportation planning studies)

Percent 0 to 6,000 lb Truck VMT = 8.55 (LDT VMT)

Percent 6,000 to 14,000 lb Truck VMT = 3.15 (MDV VMT)

Percent over 14,000 lb Truck VMT = 5.0 (HDV VMT)

Percent Automobile + LDT VMT = 91.85 (LDV VMT = Automobile VMT + LDT VMT)

Table 8-10. Total Truck Registration -- New York City (Five Boroughs)

State and City	Population	Passenger Cars Registered	Trucks Registered (by GVW Class, lb)							
			Less than 6,000	6,000 to 10,000	10,000 to 14,000	14,000 to 16,000	16,000 to 19,500	19,500 to 26,000	26,000 to 33,000	Over 33,000	Total
New York State	18,236,967	6,224,601	373,812	163,609	2,681	25,753	28,513	62,612	24,070	29,276	710,326
LDVs		6,598,413									
MDVs				166,290							
HDVs						170,224					
AQCR New York City	7,894,862	1,656,695	46,517	22,249	777	7,955	6,755	18,728	5,849	6,830	115,660
Bronx	1,471,701	258,349	6,063	2,864	88	817	736	1,872	668	887	13,995
Kings	2,602,012	504,620	13,818	5,948	217	2,058	1,905	5,209	1,662	2,460	33,277
New York	1,539,233	189,932	10,045	5,570	216	2,808	2,329	6,420	1,980	1,314	30,682
Queens	1,986,473	589,586	13,536	6,412	225	1,992	1,576	4,803	1,354	1,782	31,680
Richmond	295,443	114,208	3,055	1,455	31	280	209	424	185	387	6,026
LDVs		1,703,212									
MDVs				23,026							
HDVs						46,117					

Automobiles + Trucks = 1,656,695 + 115,660 = 1,772,355

Percent Automobiles = 93.47

Percent Trucks = 6.53

Percent 0 to 6,000 lb Trucks = 2.62 (40.22 percent of all trucks)

Percent 6,000 to 14,000 lb Trucks = 1.30 (19.91 percent of all trucks)

Percent over 14,000 lb Trucks = 2.60 (39.87 percent of all trucks)

Percent Automobile VMT = 89.8 (from transportation planning studies)

Percent Truck VMT = 10.2 (from transportation planning studies)

Percent 0 to 6,000 lb Truck VMT = 4.10 (LDT VMT)

Percent 6,000 to 14,000 lb Truck VMT = 2.03 (MDV VMT)

Percent over 14,000 lb Truck VMT = 4.07 (HDV VMT)

Percent Automobile + LDT VMT = 93.9 (LDV VMT = Automobile VMT + LDT VMT)

Subtotal counts of LDVs, MDVs, and HDVs are also shown in each table, where the LDV class encompasses both passenger cars and trucks weighing 6000 lb or less. The percent breakdown of automobiles and trucks (including GVW breakdown) is also summarized at the bottom of each table for the AQCR. Similar values for the split of VMT in the AQCR are provided, based on the basic VMT split between passenger cars and trucks as given previously in Table 8-1.

The percent breakdown values for automobiles and trucks are summarized in Table 8-11 for the United States and for the areas previously depicted in Table 8-1. Based on this registration-by-county-derived data base, the characteristic of decreasing percent of trucks as the area increases in population density is clearly shown by the Phoenix-Tucson, Los Angeles, and New York City AQCRs. The anomaly of Manhattan logically infers that in such smaller, highly populated, traffic-congested areas the percent trucks increases because of: (a) the continued need to provide goods and services for the people in the area, and (b) the concurrent difficulty of owning, storing, and/or operating passenger cars in such areas.

As shown in the table, the distribution of light-duty trucks (less than 6000-lb GVW) appears to uniformly vary inversely with population density, decreasing in percentage of total trucks as the population density increases. Except for Los Angeles, the MDV distribution appears not to be affected by population density, but rather to remain near the national average. In the Los Angeles case, this anomaly may be the result of the widespread use of heavier camper bodies and motor homes used for recreational purposes. Thus, the distribution between LDTs and MDVs may be a logical result of region-peculiar use characteristics in Los Angeles.

The HDVs, on the other hand, increase in distribution as percent of total trucks in accordance with increasing population density. Again, this may be the logical result of the need for heavy trucks to move goods into the heavily populated areas in accordance with the number of inhabitants involved.

Table 8-11. Vehicle Registration Breakdown by Location -- 1 July 1972

Based on 1 July 1972 cars in operation and trucks in operation surveys by R. L. Polk Company

Parameter	Area						
				New York City Areas			
	Nation	Phoenix-Tucson AQCR	South Coast Air Basin AQCR (Los Angeles)	Tri-State (New York City AQCR)	Nine Counties	New York City (Five Boroughs)	Manhattan
Total Number of Vehicles	106,211,895	941,697	5,802,658	6,637,845	3,722,530	1,772,355	220,614
Percent Automobiles	81.38	75.91	83.75	92.1	92.86	93.47	86.09
Percent Trucks	18.62	24.09	16.25	7.91	7.14	6.53	13.91
Truck Percent of Total Vehicles by GVW Class							
0 to 6,000 lb	12.06	17.67	9.68	4.05	3.26	2.62	4.55
6,000 to 14,000 lb	3.56	4.47	4.82	1.49	1.60	1.30	2.63
Over 14,000 lb	3.00	1.95	1.75	2.37	2.28	2.61	6.73
Percent of Total Trucks by GVW Class							
0 to 6,000 lb	64.79	73.40	59.55	51.20	45.59	40.22	32.74
6,000 to 14,000 lb	19.09	18.50	29.70	18.89	22.47	19.91	18.86
Over 14,000 lb	16.12	8.10	10.75	29.91	31.94	39.87	48.40

8.3 SUMMARY

Because of the lack of uniformity in the data bases used in various transportation planning studies (Section 8.1), it is felt that the vehicle location and characteristics by GVW breakdown provided by the R. L. Polk Company registration surveys (Section 8.2) is a more consistent and reliable data base to characterize vehicles located in the AQCRs of interest. However, there is no similar basis for providing VMTs for these regions. Accordingly, the data of Table 8-1 are revised in Table 8-12 to retain the previously developed VMTs and to incorporate the vehicle percentage distribution values of Table 8-11 and the corresponding VMT splits by vehicle class as described in Tables 8-7 through 8-10. One other change was also made. The values reported in Table 8-1 for the New York AQCR (Tri-State) are felt to be for the Tri-State region as defined by the Tri-State Transportation Planning Commission. The New York AQCR encompasses a slightly smaller area (17,402,249 people versus 18,700,000 people in Table 8-1). Therefore, the population, total vehicles, and total daily VMT for the New York AQCR have been revised downward in Table 8-12 by the ratio 17,402,249/18,700,000. As shown, Table 8-12 is felt to exemplify the most accurate available representation of the AQCRs of interest for the parameters displayed.

Table 8-12. Vehicle Miles Traveled Data Summary -- Circa 1970

Parameter	Area							
				New York City Areas				
	Nation	Phoenix-Tucson AQCR	South Coast Air Basin AQCR (Los Angeles)	Tri-State (New York City AQCR)	Nine Counties	New York City (Five Boroughs)	Manhattan (New York County)	Downtown Manhattan
Population	--	1,429,000	9,700,000	17,402,249	11,560,000	7,890,000	1,590,000	
Total Number of Vehicles[a]	106,211,895	821,000	5,600,000	6,793,490	3,659,000	1,762,000	231,000	
Percent Automobiles[b]	81.38	75.91	83.75	92.1	92.86	93.47	86.09	
Percent Trucks[b]	18.62	24.09	16.25	7.9	7.14	6.53	13.91	
Truck GVW Breakdown[b] (Percent)								
0 to 6,000 lb (LDT)	64.79	73.4	59.55	51.20	45.59	40.22	32.74	
6,000 to 14,000 lb (MDV)	19.09	18.5	29.70	18.89	22.47	19.91	18.86	
Over 14,000 lb (HDV)	16.12	8.1	10.75	29.91	31.94	39.87	48.40	
Total Daily VMT[a]		17,000,000	150,000,000	169,369,470	99,000,000	34,146,000	6,035,000	
Percent VMT by Trucks[a]		17.3	13.5	16.7	--	10.2	17.3	42.0
Truck VMT Breakdown[c] (Percent)								
0 to 6,000 lb		73.4	59.55	51.20	45.59	40.22	32.74	32.74
6,000 to 14,000 lb		18.5	29.70	18.89	22.47	19.91	18.86	18.86
Over 14,000 lb		8.1	10.75	29.91	31.94	39.87	49.40	49.40
VMT/Vehicle[a]		20.7	26.8	25.0	27.3	19.3	26.1	
VMT/Truck[a]		14.87	22.25	52.7	--	30.27	32.49	
Percent VMT								
LDV (Automobiles + LDT)		95.4	94.54	91.85		93.9	88.19	71.4
MDV		3.2	4.0	3.15		2.03	3.26	7.9
HDV		1.4	1.46	5.0		4.07	8.55	20.7

[a] From various transportation planning studies

[b] Based on 1 July 1972 registration data for both passenger cars and trucks provided by R. L. Polk Company

[c] Assumed to be the same as GVW breakdown

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SECTION 9

EMISSION INVENTORIES

Inventories of mobile source emissions were calculated for the New York City, Los Angeles, and Phoenix-Tucson AQCRs. These inventories included a breakdown by vehicle class (LDV, MDV, and HDV) and were projected to the year 1990 to reflect the effects of various possible MDV control strategies. The base year in all cases was 1970; the vehicle distribution and VMT characteristics of Figure 8-12 for 1970 were used for the AQCRs examined. Details of the calculational procedure are given in Appendix E. The following sections delineate the major input parameter assumptions and the inventory results.

9.1 EMISSION LEVEL ASSUMPTIONS

9.1.1 Light-Duty Vehicles

For all model years, except 1975 and 1976, the values as shown in Ref. 9-1 were used as characteristic of LDV emission rates and deterioration-with-age factors. For 1975, the changed emission factors and deterioration factors used are shown in Tables 9-1 and 9-2, respectively. These values reflect the current difference in LDV exhaust emission regulations between California and the other states. For 1976 (and all later model years), the values in Ref. 9-1 were used, except for the 1976 NO_x low mileage emission level. This was raised to the 1975 zero mile level of 1.60 gm/mi for California and 2.2 gm/mi for the other AQCRs.

9.1.2 Medium-Duty Vehicles

Table 9-3 lists the values of MDV emission factors used through model year 1973. These values are based on composite sales-weighted test values (Ref. 9-3); therefore, no deterioration factors should be applied to them. For model years 1974 and beyond, four scenarios or alternative MDV control strategy postulates were considered, as shown in Table 9-4.

Table 9-1. Light-Duty Vehicle Exhaust Emission Factors at Low Mileage -- Model Year 1975 (Ref. 9-2)

Pollutant	New York City and Phoenix-Tucson Rate, gm/mi	Los Angeles Rate, gm/mi
Hydrocarbon	1.3	0.33
Carbon Monoxide	12.5	2.80
Oxides of Nitrogen	2.2	1.60

Table 9-2. Light-Duty Vehicle Deterioration Factors -- Model Year 1975

Pollutant	Vehicle Age, years									
	0	1	2	3	4	5	6	7	8	9 or older
New York City and Phoenix-Tucson AQCRs[a]										
Hydrocarbon	1.00	1.00	1.13	1.22	1.29	1.37	1.43	1.50	1.56	1.63
Carbon Monoxide	1.00	1.04	1.30	1.36	1.43	1.44	1.49	1.56	1.63	1.69
Oxides of Nitrogen	1.00	1.00	1.18	1.23	1.23	1.41	1.45	1.45	1.45	1.45
Los Angeles AQCR[b]										
Hydrocarbon	1.00	1.45	1.95	2.40	2.76	3.14	3.46	3.79	4.07	4.42
Carbon Monoxide	1.00	1.34	1.77	2.14	2.42	2.73	2.99	3.26	3.48	3.77
Oxides of Nitrogen	1.00	1.11	1.18	1.20	1.21	1.22	1.23	1.24	1.25	1.26

[a] From Ref. 9-2

[b] From Ref. 9-1 for California

Table 9-3. Medium-Duty Vehicle Exhaust Emission Factors for All AQCRs -- To Model Year 1973 (Ref. 9-3)

Factors represent combined averages of initial emission rates and deterioration factors; therefore, no deterioration factors should be applied.

Model Year	Emission Values, gm/mi		
	Hydrocarbon	Carbon Monoxide	Oxides of Nitrogen
Pre-1967	12.39	103.99	6.21
1967	11.41	122.40	6.49
1968	10.98	122.47	6.56
1969	8.64	99.07	7.20
1970	6.38	75.43	8.23
1971	6.29	70.90	8.60
1972	5.31	61.87	8.21
1973	5.30	62.08	6.57

Strategy I represents the situation where the MDV is characterized by HDV engines meeting the 1974 Federal HDV standards, with no further changes taking place.

Strategy II, in California, further represents the case of the MDV reflecting the changes in California 1975 HDV engine emission standards in 1975. This same change is assumed to occur in the rest of the United States in 1977.

Strategy III depicts the case where oxidation catalyst plus EGR are added to MDVs, in California in 1977 and the rest of the United States in 1979.

Strategy IV represents a further case, where a reducing catalyst (or other equivalent) is added to MDVs for ultralow NO_x emissions, in California in 1980 and in the rest of the United States in 1982.

Table 9-4. Medium-Duty Vehicle Exhaust Emission Factors -- Model Year 1974 and Later

Strategy and Model Year	New York City and Phoenix-Tucson AQCRs			Los Angeles AQCR		
	Hydrocarbon	Carbon Monoxide	Oxides of Nitrogen	Hydrocarbon	Carbon Monoxide	Oxides of Nitrogen
Strategy I						
1974	4, 25[a]	62, 08[a]	6, 57[a]	4, 25[a]	62, 08[a]	6, 57[a]
1975	4, 25	62, 08	6, 57	4, 25	62, 08	6, 57
1976 and Later	4, 25	62, 08	6, 57	4, 25	62, 08	6, 57
Strategy II						
1974	4, 25	62, 08	6, 57	4, 25	62, 08	6, 57
1975	4, 25	62, 08	6, 57	1, 33[b]	38, 8[c]	2, 06[d]
1976	4, 25	62, 08	6, 57	1, 33	38, 8	2, 06
1977 and Later	1, 33[b]	38, 8[c]	2, 06[d]	1, 33	38, 8	2, 06
Strategy III						
1974	4, 25	62, 08	6, 57	4, 25	62, 08	6, 57
1975	4, 25	62, 08	6, 57	1, 33[b]	38, 8[c]	2, 06[d]
1976	4, 25	62, 08	6, 57	1, 33	38, 8	2, 06
1977	1, 33[b]	38, 8[c]	2, 06[d]	0, 40[e]	4, 20[e]	2, 06
1978	1, 33	38, 8	2, 06	0, 40	4, 20	2, 06
1979 and Later	0, 40[e]	4, 20[e]	2, 06	0, 40	4, 20	2, 06
Strategy IV						
1974	4, 25	62, 08	6, 57	4, 25	62, 08	6, 57
1975	4, 25	62, 08	6, 57	1, 33[b]	38, 8[c]	2, 06[d]
1976	4, 25	62, 08	6, 57	1, 33	38, 8	2, 06
1977	1, 33[b]	38, 8[c]	2, 06[d]	0, 40[e]	4, 20[e]	2, 06
1978	1, 33	38, 8	2, 06	0, 40	4, 20	2, 06
1979	0, 40[e]	4, 20[e]	2, 06	0, 40	4, 20	2, 06
1980	0, 40	4, 20	2, 06	0, 40	4, 20	0, 45[e]
1981	0, 40	4, 20	2, 06	0, 40	4, 20	0, 45
1982 and Later	0, 40	4, 20	0, 45[e]	0, 40	4, 20	0, 45

[a] The 1974 levels are assumed the same as 1973 levels (Table 9-3) except for HC, which was estimated to be reduced 20 percent from 1973 level (Ref. 9-4).

[b] 1, 33 = 5/16 × 4, 25
[c] 38, 8 = 25/40 × 62, 08
[d] 2, 06 = 5/16 × 6, 57
Reduced values determined by applying ratio of California 1975 HDV standards/Federal 1974 standards to prior values (see Table 3-9).

[e] Estimated values based on predictive techniques developed in Section 3.

9.1.3 Heavy-Duty Vehicles

Table 9-5 lists the values of HDV emission factors used through model year 1974. These values are composite average values (Ref. 9-4); therefore, no deterioration factors should be applied to them. For model years 1974 and beyond, two scenarios or alternative HDV control strategy postulates were also considered, as shown in Table 9-6.

Strategy I represents the case where there is no further change in HDV emission regulations (Federal 1974 HDV standards stay in effect).

Strategy II represents the case where the California 1975 HDV standards are implemented, in California in 1975 and in the rest of the United States in 1977.

Strategy I was used with MDV Strategy I and Strategy II was used with MDV Strategies II, III, and IV.

9.2 GROWTH RATE ASSUMPTIONS

Anticipated mobile source growth rates for all vehicle classes were chosen equal to the forecasted adult population increase (18 years or older) reduced to a yearly basis (Ref. 9-5). In the case of passenger cars,

Table 9-5. Heavy-Duty Exhaust Emission Factors -- To Model Year 1974 (Ref. 9-4)

Factors represent combined averages of initial emission rates and deterioration factors; therefore, no deterioration factors should be applied.

Model Year	Emission Values, gm/mi		
	Hydrocarbon	Carbon Monoxide	Oxides of Nitrogen
Pre-1970	23.4	192	12.9
1970 to 1973	22.0	179	12.6
1974	17.9	179	12.6

Table 9-6. Heavy-Duty Vehicle Exhaust Emission Factors -- Model Year 1974 and Later

Strategy and Model Year	New York City and Phoenix-Tucson AQCRs			Los Angeles AQCR		
	Hydro-carbon	Carbon Monoxide	Oxides of Nitrogen	Hydro-carbon	Carbon Monoxide	Oxides of Nitrogen
Strategy I						
1974	17.9[a]	179[a]	12.6[a]	17.9[a]	179[a]	12.6[a]
1975	17.9	179	12.6	17.9	179	12.6
1976 and Later	17.9	179	12.6	17.9	179	12.6
Strategy II						
1974	17.9	179	12.6	17.9	179	12.6
1975	17.9	179	12.6	5.6[b]	112[c]	3.94[d]
1976	17.9	179	12.6	5.6	112	3.94
1977 and Later	5.6[b]	112[c]	3.94[d]	5.6	112	3.94

[a] Emission factors from Table 9-5

[b] 5.6 = 5/16 × 17.9
[c] 112 = 25/40 × 179
[d] 3.94 = 5/16 × 12.6

Reduced values determined by applying ratio of California 1975 HDV standards/Federal 1974 standards to prior values (see Table 3-5)

an additional growth factor was applied to account for present trends of ownership of multiple cars per family (see Appendix E for details).

The overall annual growth rates thus selected for each AQCR are listed in Table 9-7. To illustrate the effect of growth rate on the magnitude of mobile-source-generated emissions, a high-rate growth factor of [illegible] percent per year was applied uniformly to all vehicle classes (LDVs, MDVs, and HDVs) in the New York City AQCR only (Section 9.3.1).

Table 9-7. Mobile Source Annual Growth Rates

AQCR	Percent per Year	
	Passenger Cars	Trucks
New York City	1.245	1.180
Los Angeles	1.248	1.197
Phoenix-Tucson	1.235	1.200

9.3 INVENTORY RESULTS

9.3.1 New York City AQCR

Figures 9-1, 9-2, and 9-3 illustrate the variation with time of the New York City AQCR mobile source (LDVs, MDVs, and HDVs) emission inventory for HC, CO, and NO_x, respectively. These figures include the anticipated vehicle population growth rates of Table 9-7. In all cases, there is a steady decline in total emissions, with all control strategies reaching an apparent plateau level in the 1985 to 1990 time period.

With no further emission control beyond the presently-established LDV regulations and the 1974 HDV emission standards (Strategy No. I), the HC emissions are reduced in 1990 to approximately 24 percent of 1970 levels, CO to 28 percent, and NO_x to 38 percent.

Implementation of MDV and HDV standards in 1977 equivalent to the California 1975 HDV standards (Strategy No. II) results in further sizable reductions by 1990. The HC emissions are reduced to approximately 15 percent of 1970 levels, CO to 21 percent, and NO_x to 21 percent.

The addition of oxidation catalysts to MDVs in 1979 (Strategy No. III) has relatively little effect because of the relatively small MDV population and VMT contribution. The addition of a reducing catalyst to MDVs in 1982 (Strategy No. IV) also has a small effect for the same reason.

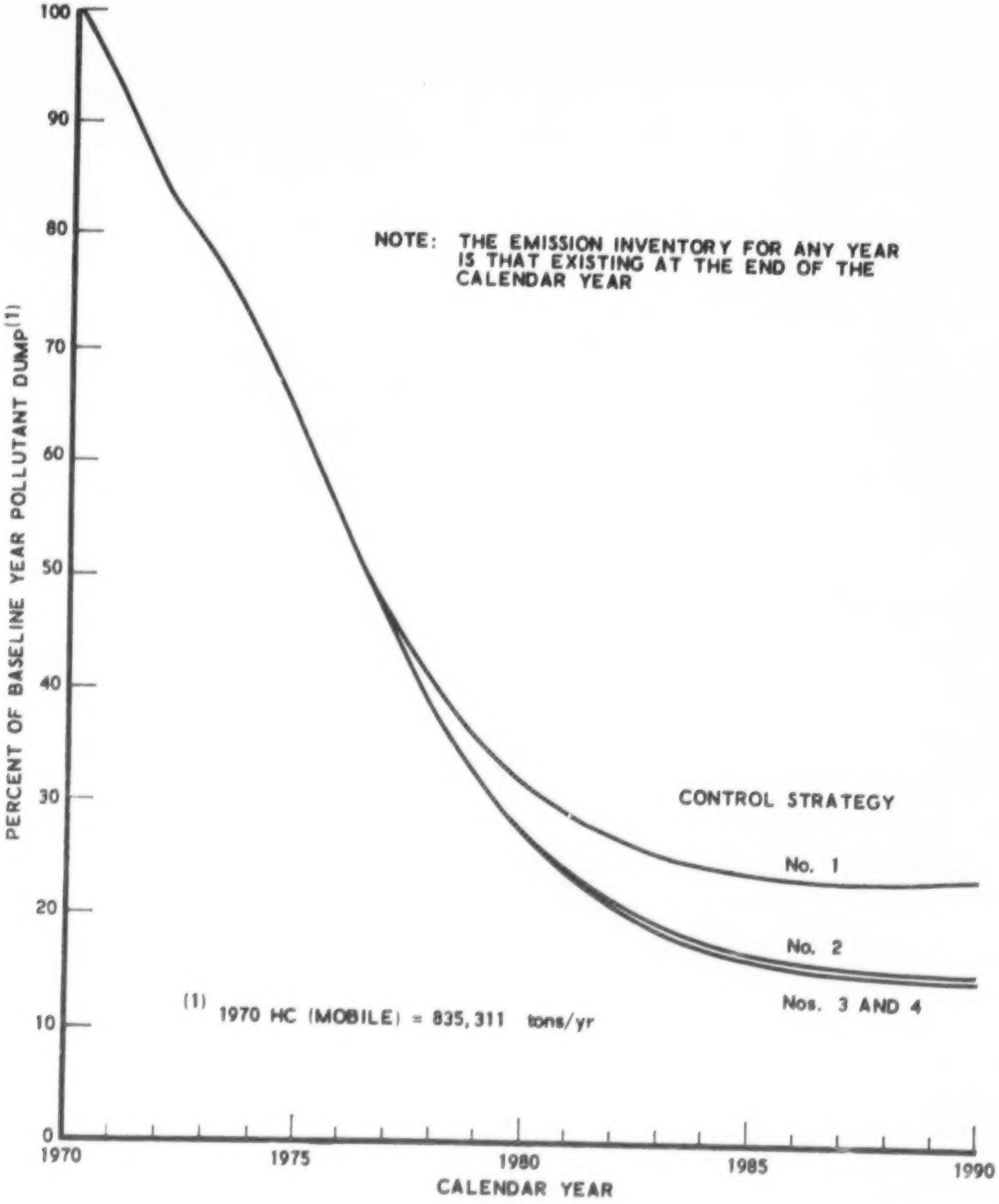

Figure 9-1. New York City AQCR -- Mobile Source HC Inventory (Determined Using Anticipated Normal Growth Rates from Table 9-7)

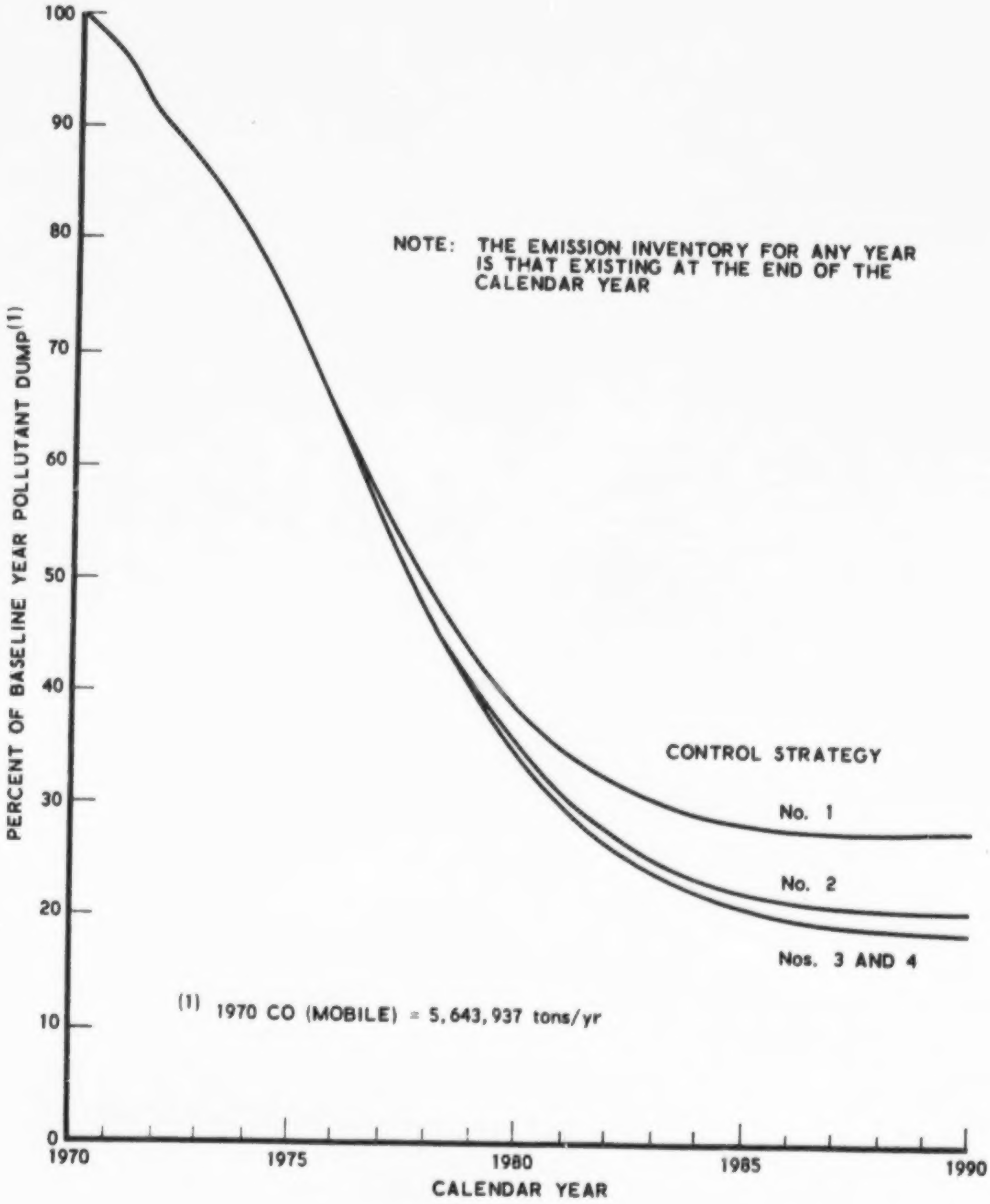

Figure 9-2. New York City AQCR -- Mobile Source CO Inventory (Determined Using Anticipated Normal Growth Rates from Table 9-7)

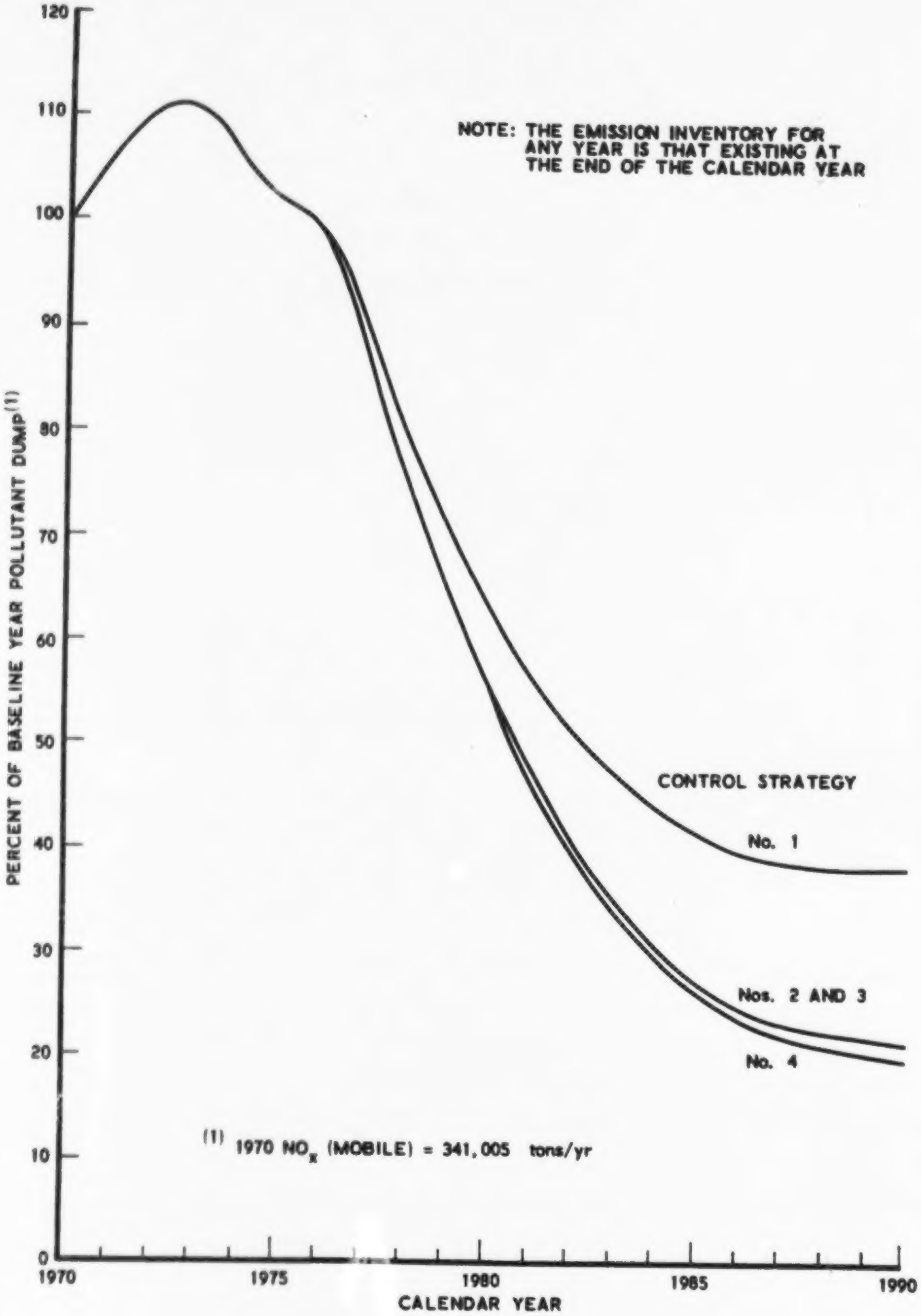

Figure 9-3. New York City AQCR -- Mobile Source NO_x Inventory (Determined Using Anticipated Normal Growth Rates from Table 9-7)

Figures 9-4, 9-5, and 9-6 show similar values for the New York City AQCR if the growth rates for all vehicle classes were 4 percent per year. Although the overall trends parallel those of Figures 9-1, 9-2, and 9-3, the absolute levels are higher because of the higher vehicle population. Also, the minimum plateau for HC, CO, and NO_x total emissions appears to be reached by approximately 1985, with total emissions rising again in 1990.

Figures 9-7, 9-8, and 9-9 depict the percentage contribution of the LDV, MDV, and HDV classes to the emission inventories of Figures 9-1, 9-2, and 9-3, respectively. In all cases, the HDVs contribute proportionally higher amounts of emissions with time; by 1985 producing more pollutants than LDVs under control Strategy No. I. Under control Strategy No. II, the HDV HC and NO_x percentage is markedly reduced, although still about three times as high as 1970 percentages in 1990. The HDV CO contributions are reduced somewhat, but are nearly five times 1970 values in 1990. Control Strategies Nos. III and IV do not markedly alter HDV emission contribution characteristics.

In the case of MDVs, their percentage contribution rises steadily with time under control Strategy No. I; by 1990, HC values are more than double 1970 values, CO values are tripled, and NO_x values quadrupled. Control Strategy No. II nearly cuts 1990 HC and NO_x values in half, but has a much lesser effect on CO. Control Strategies Nos. III and IV (oxidizing and reducing catalysts on MDVs) restore 1990 MDV values to approximately 1970 percentage levels.

9.3.2 Los Angeles AQCR

Figures 9-10, 9-11, and 9-12 are Los Angeles AQCR mobile source emission inventories for HC, CO, and NO_x, respectively. They are based on the anticipated vehicle population growth rates of Table 9-7. The trends are similar to those for the New York City AQCR (Figures 9-1, 9-2, and 9-3), only the absolute numerical levels differ slightly. In general, the 1990 HC, CO, and NO_x emissions are from 5 to 10 percent higher than New York City values (based on 1970 baseline levels).

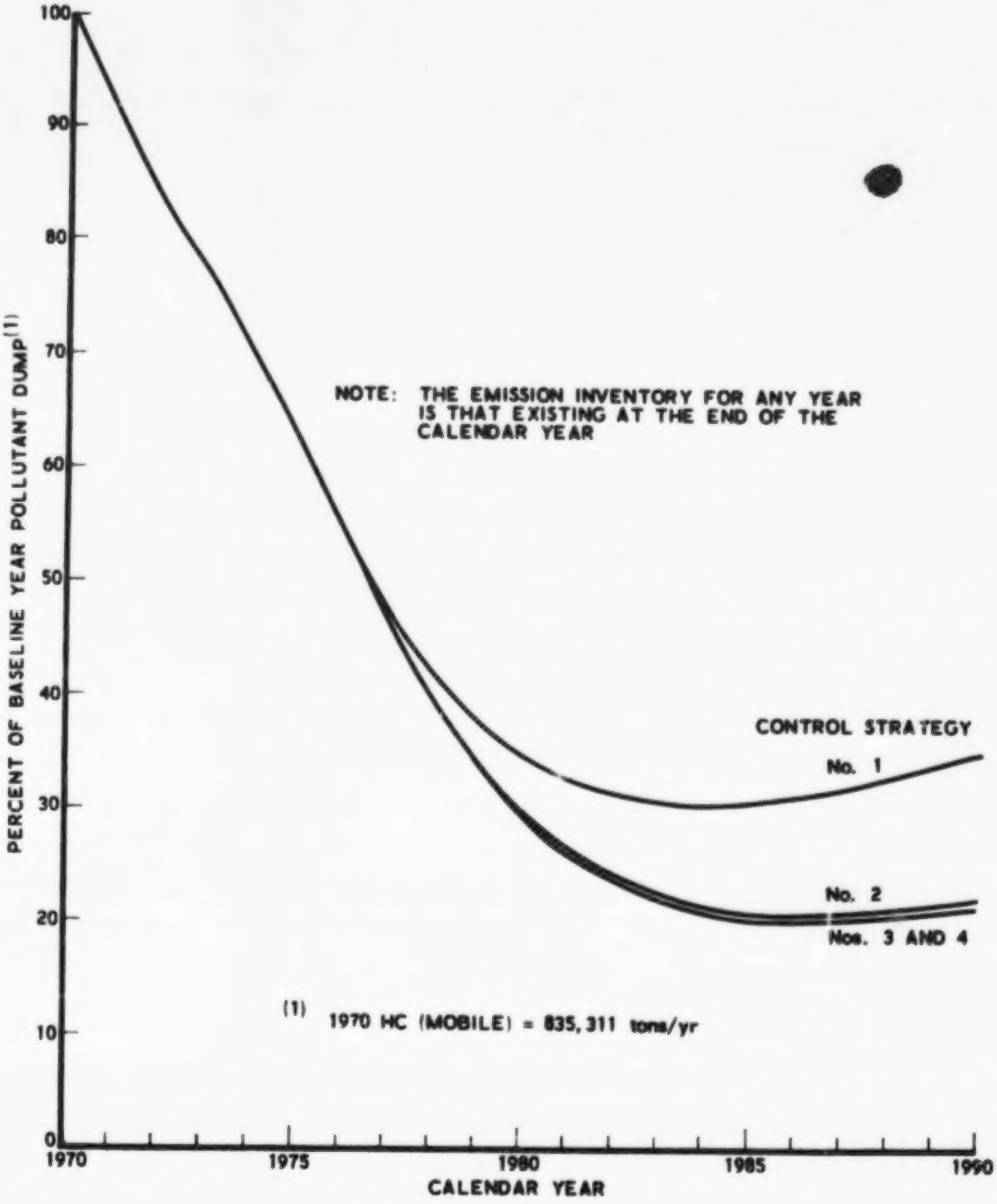

Figure 9-4. New York City AQCR -- Mobile Source HC Inventory (Determined Using Assumed 4 Percent per Year Growth Rate)

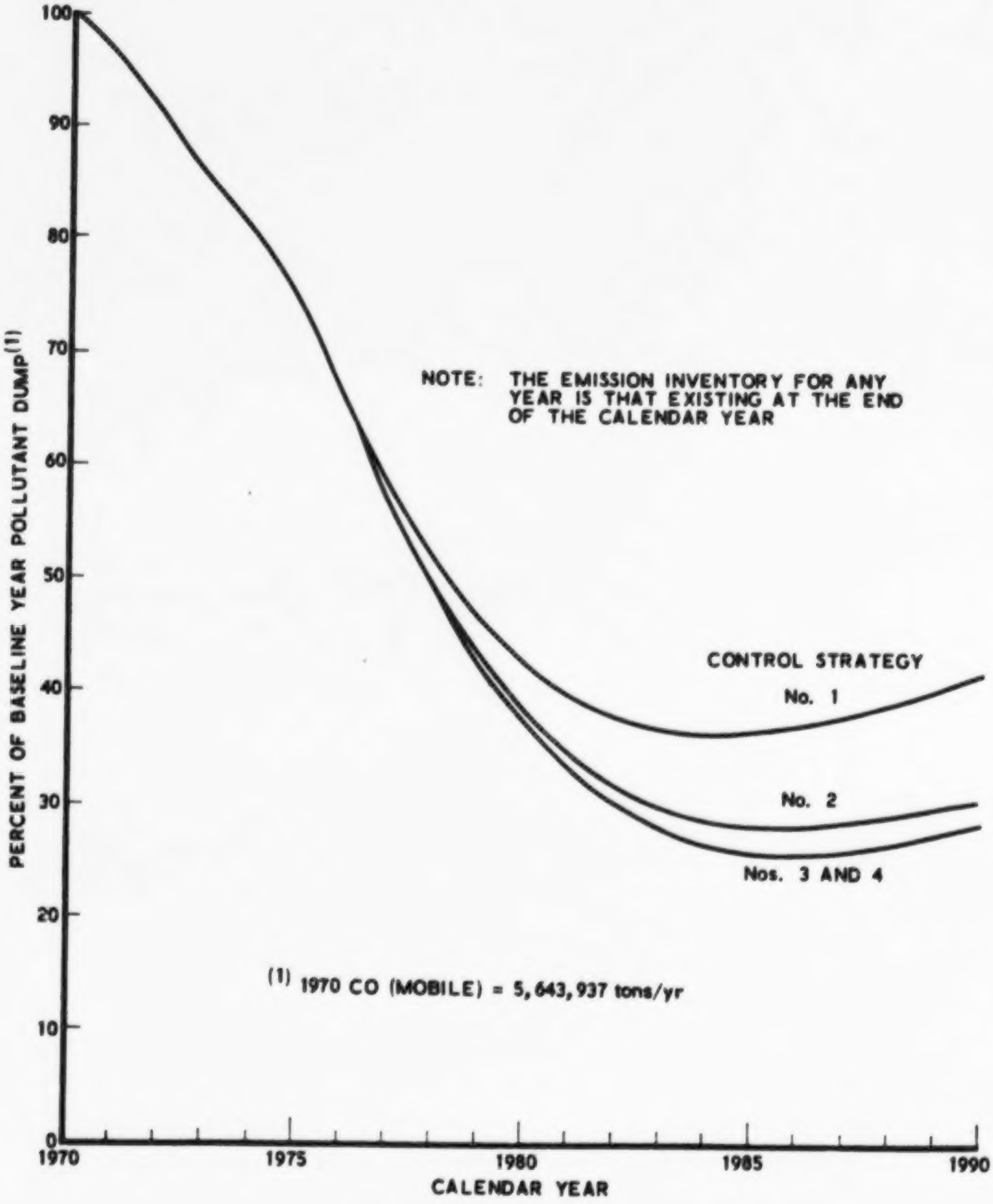

Figure 9-5. New York City AQCR -- Mobile Source CO Inventory (Determined Using Assumed 4 Percent per Year Growth Rate)

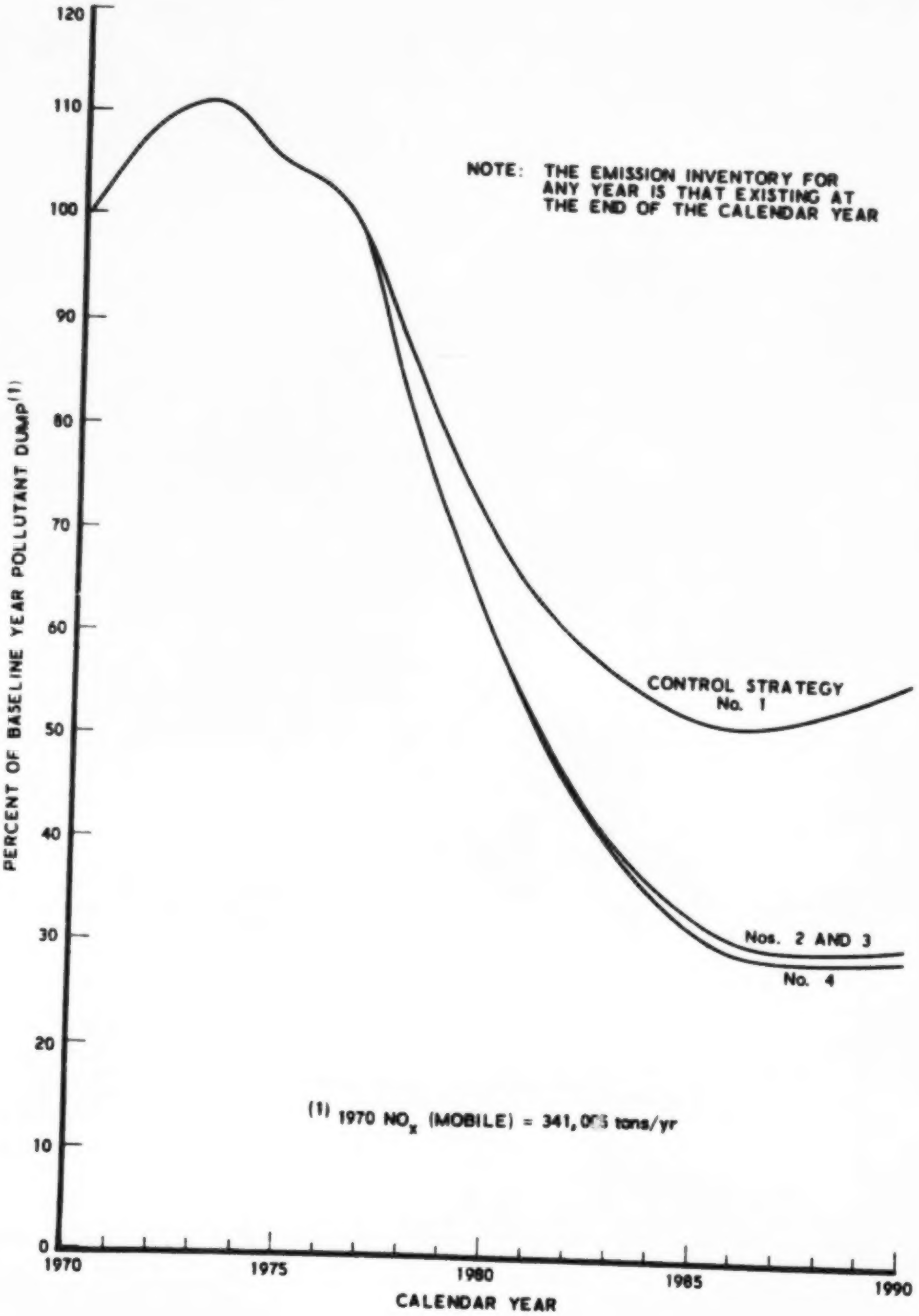

Figure 9-6. New York City AQCR -- Mobile Source NO$_x$ Inventory (Determined Using Assumed 4 Percent per Year Growth Rate)

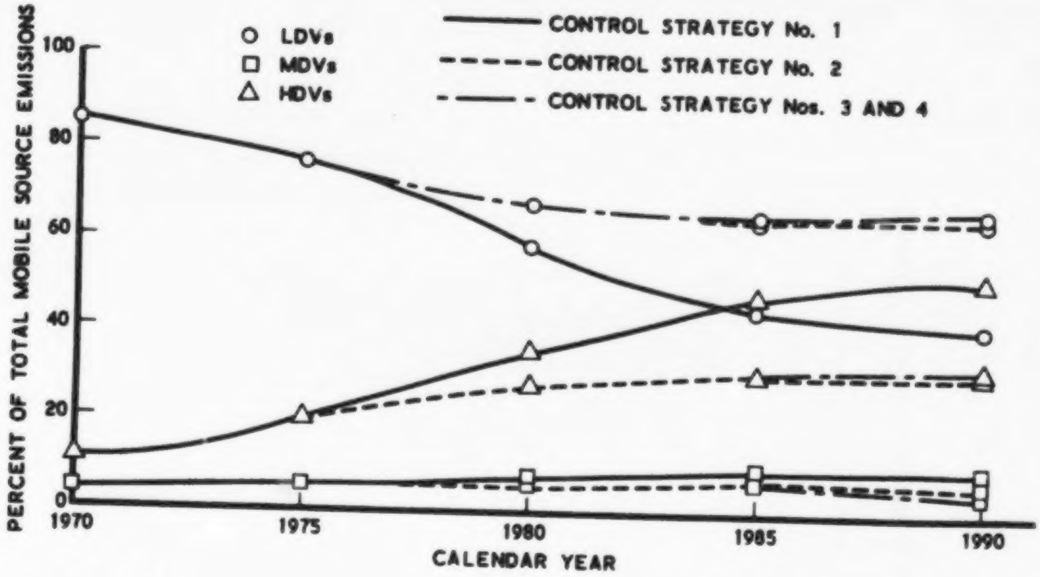

Figure 9-7. New York City AQCR -- HC Percentage Contribution of Vehicle Classes (Normal Growth Rates from Table 9-7)

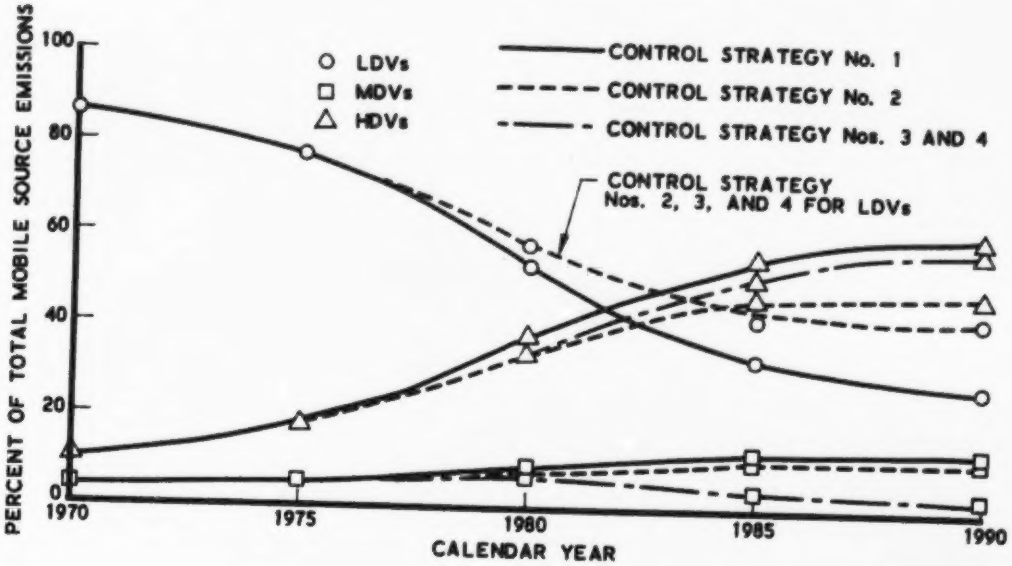

Figure 9-8. New York City AQCR -- CO Percentage Contribution of Vehicle Classes (Normal Growth Rates from Table 9-7)

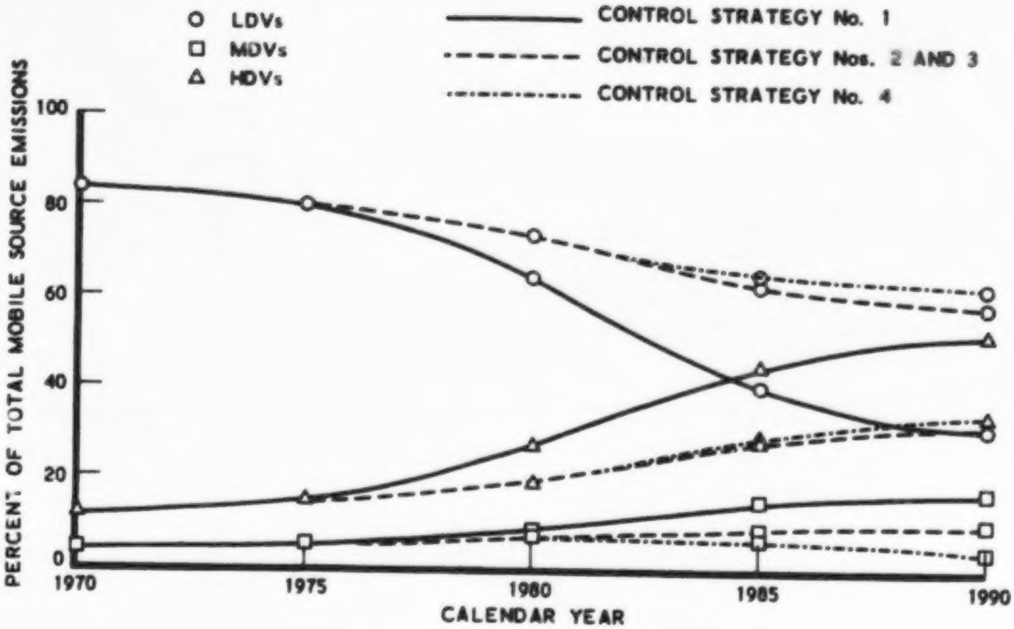

Figure 9-9. New York City AQCR -- NO_x Percentage Contribution of Vehicle Classes (Normal Growth Rates from Table 9-7)

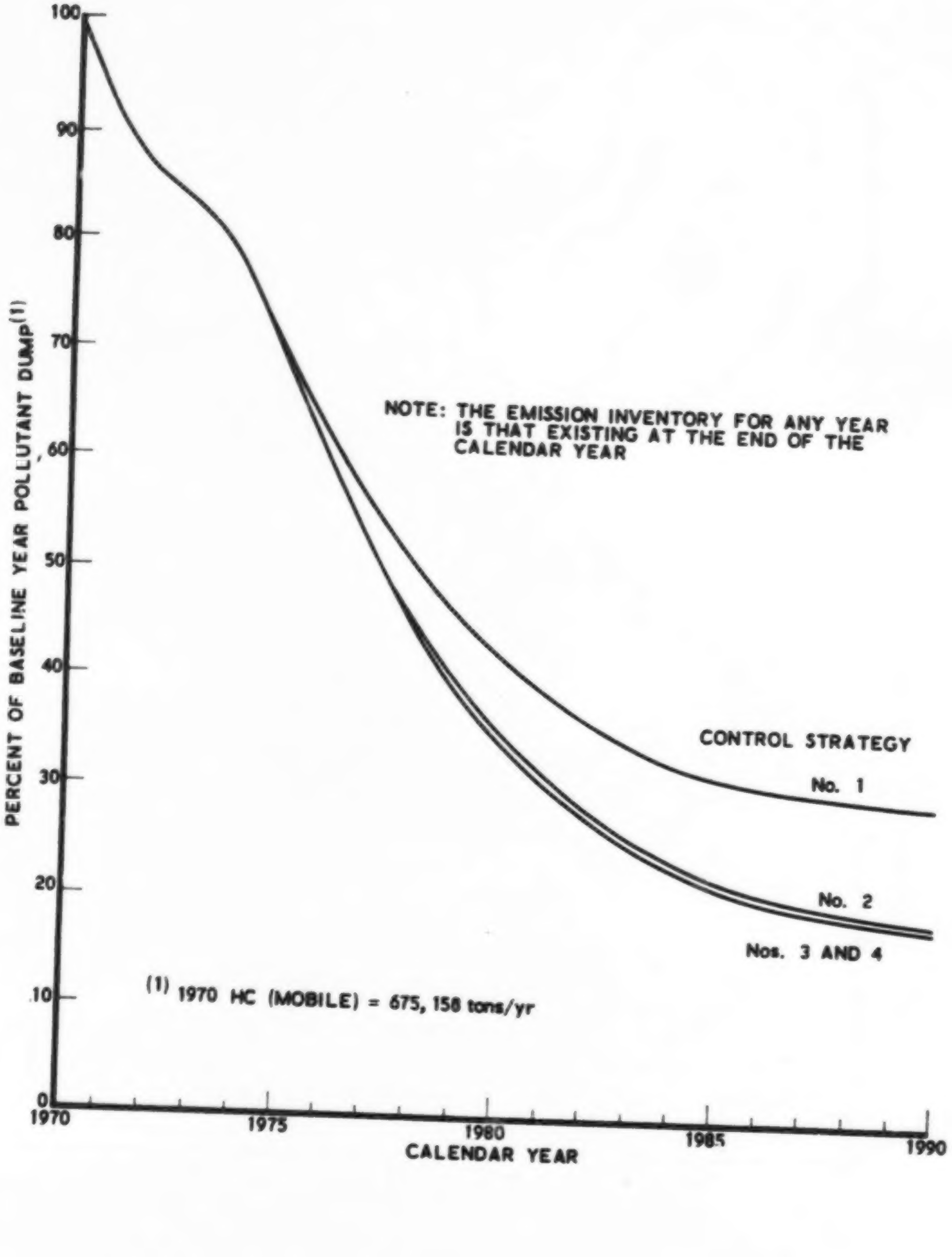

Figure 9-10. Los Angeles AQCR -- Mobile Source HC Inventory (Determined Using Anticipated Normal Growth Rates from Table 9-7)

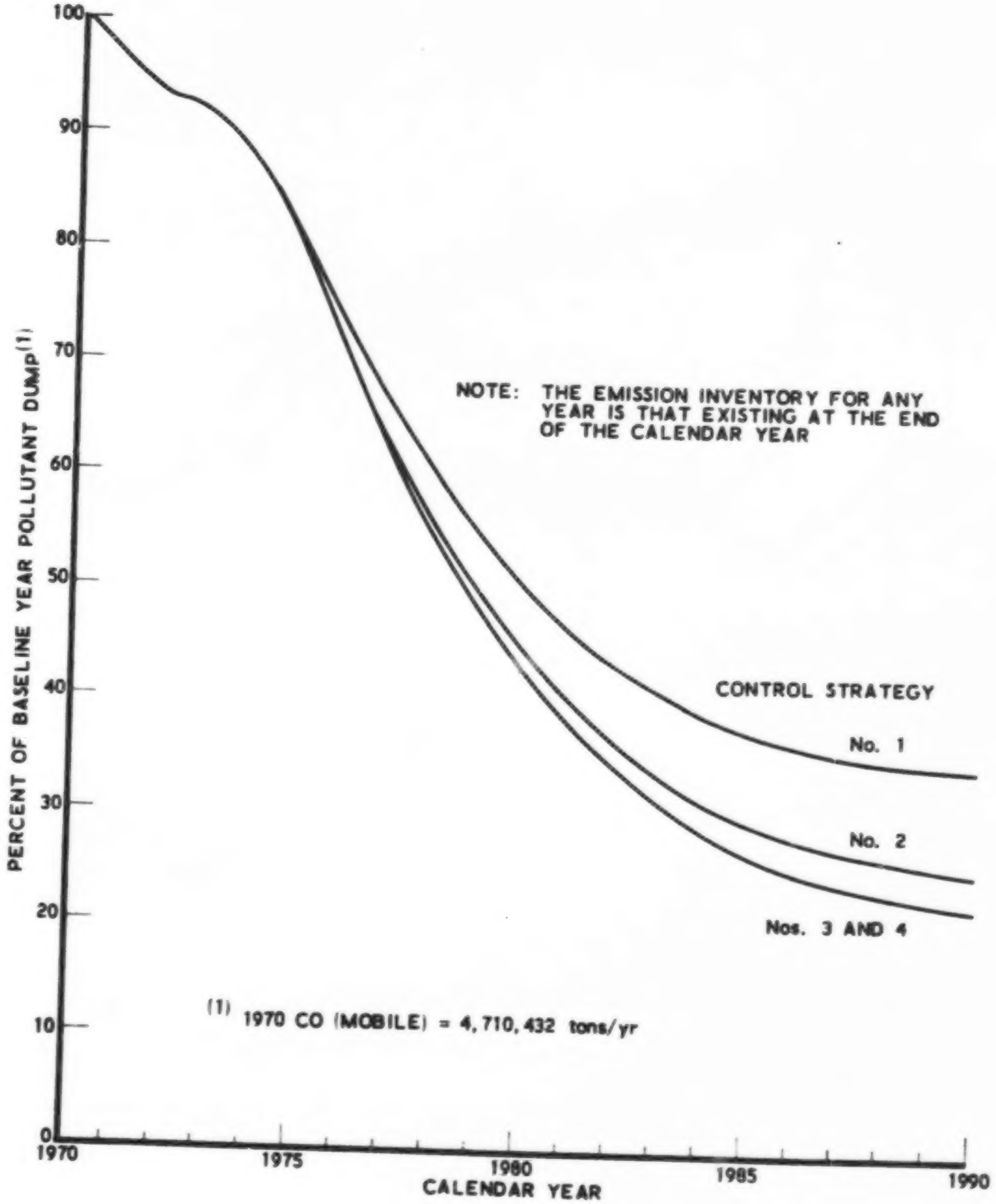

Figure 9-11. Los Angeles AQCR -- Mobile Source CO Inventory (Determined Using Anticipated Normal Growth Rates from Table 9-7)

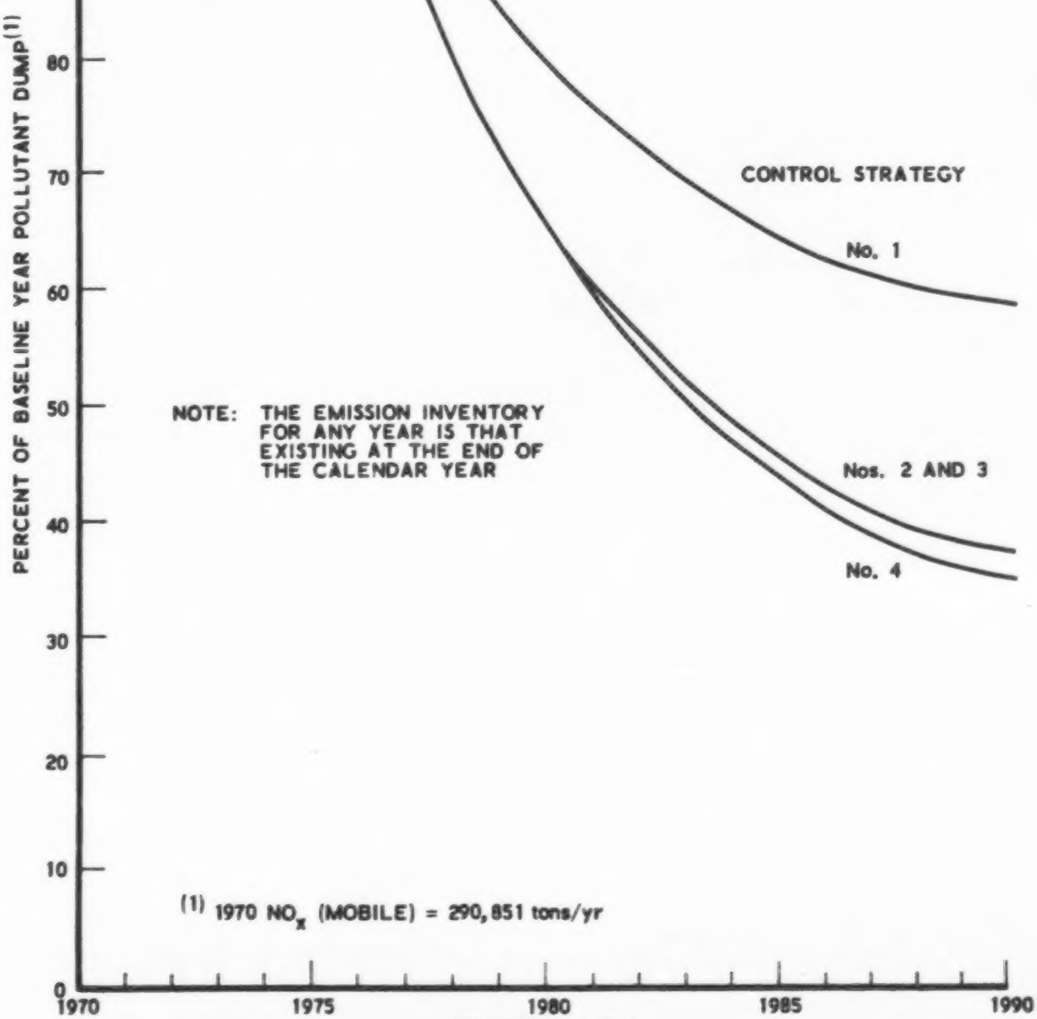

Figure 9-12. Los Angeles AQCR -- Mobile Source NO_x Inventory (Determined Using Anticipated Normal Growth Rates from Table 9-7)

Similarly, Figures 9-13, 9-14, and 9-15 depict the percentage contribution of the LDV, MDV, and HDV classes to the emission inventories of Figures 9-10, 9-11, and 9-12. Again, the trends are similar to those of the New York City AQCR (Figures 9-7, 9-8, and 9-9) and are not further discussed in the interest of brevity.

9.3.3 Phoenix-Tucson AQCR

Mobile source HC, CO, and NO_x emission inventories for the Phoenix-Tucson AQCR are illustrated in Figures 9-16, 9-17, and 9-18. Their patterns and trends are similar to those noted for New York City and Los Angeles.

The percentage contribution of the LDV, MDV, and HDV classes to these emission inventories is shown in Figures 9-19, 9-20, and 9-21. The most notable characteristic here is that the relative effect and importance of the HDV class is greatly reduced over that shown previously for New York City and Los Angeles. This is a direct result of a smaller HDV population in the Phoenix-Tucson area and a lesser VMT contribution.

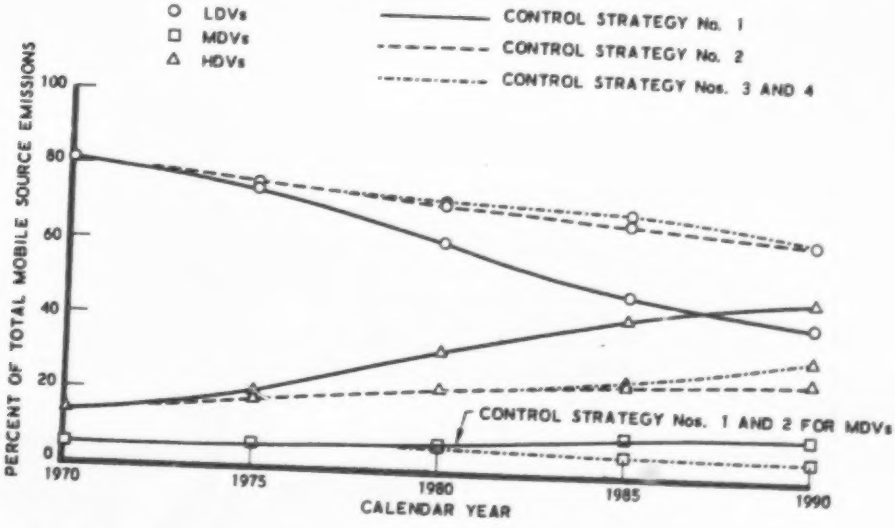

Figure 9-13. Los Angeles AQCR -- HC Percentage Contribution of Vehicle Classes (Normal Growth Rates from Table 9-7)

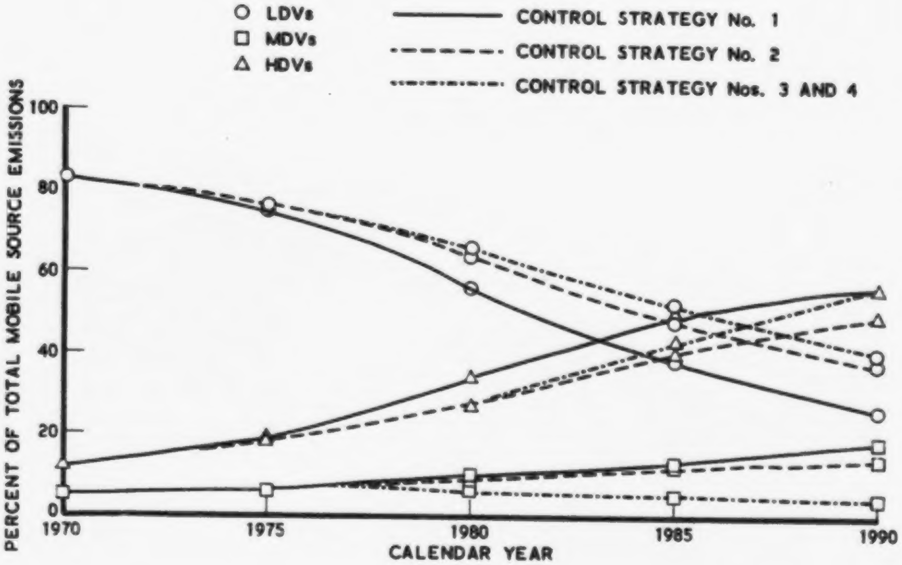

Figure 9-14. Los Angeles AQCR -- CO Percentage Contribution of Vehicle Classes (Normal Growth Rates from Table 9-7)

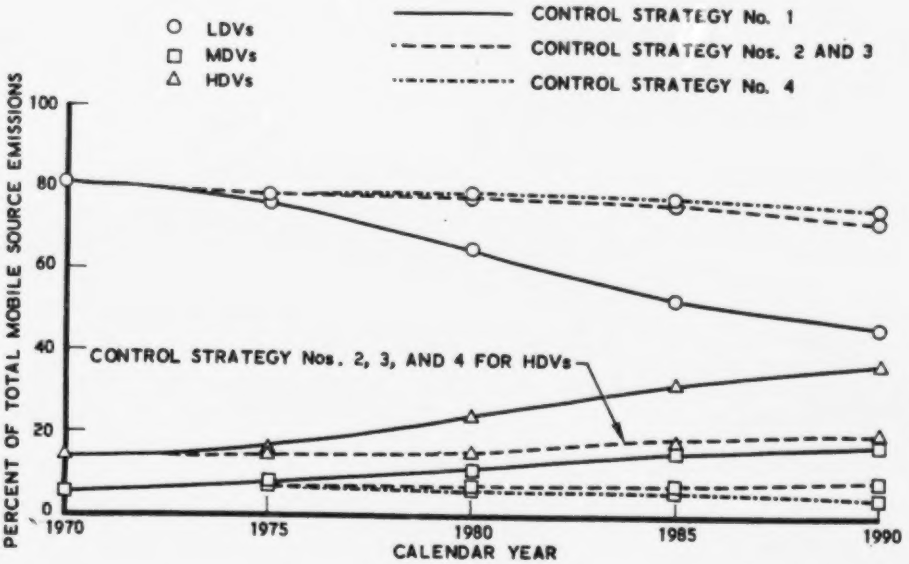

Figure 9-15. Los Angeles AQCR -- NO_x Percentage Contribution of Vehicle Classes (Normal Growth Rates from Table 9-7)

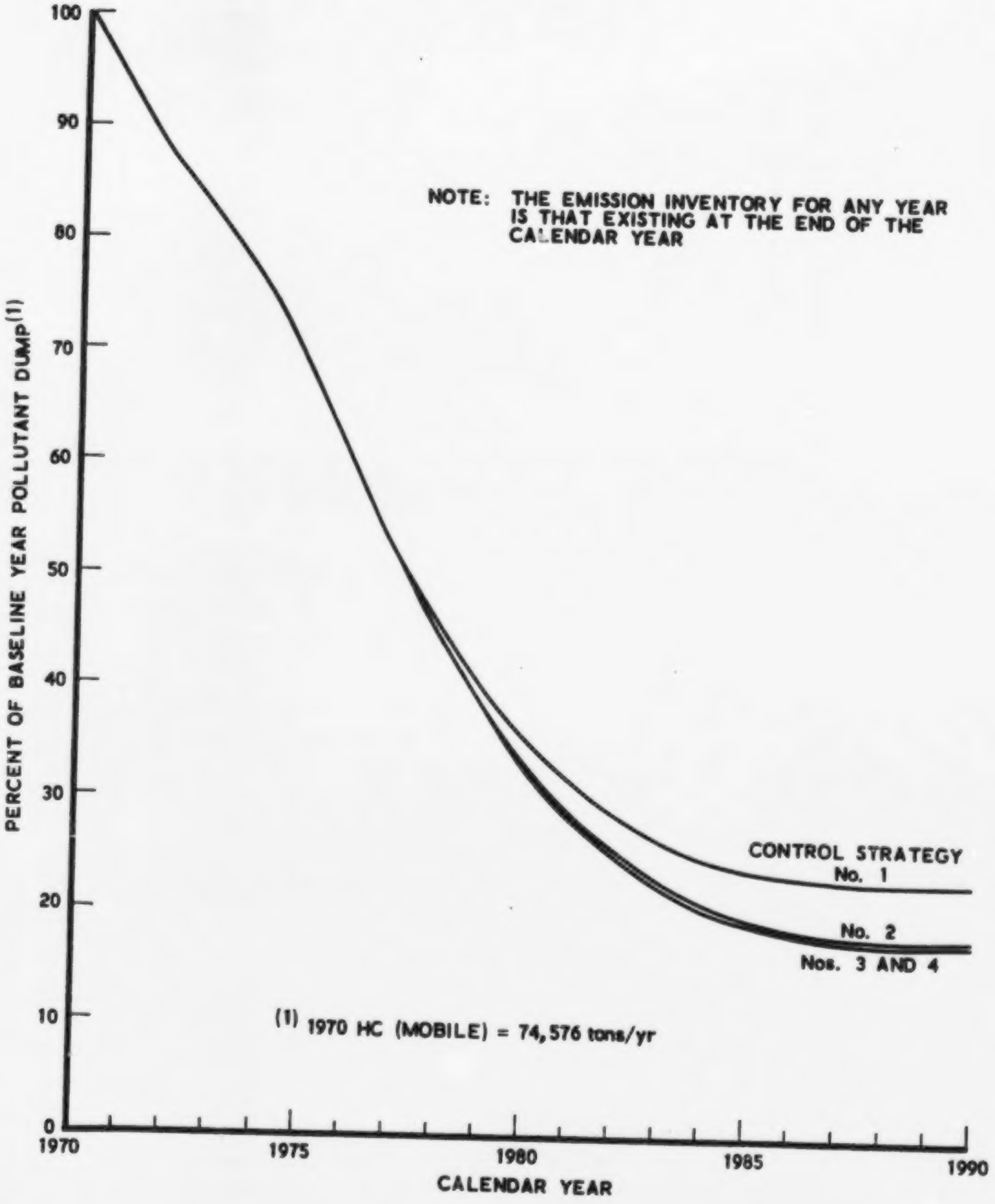

Figure 9-16. Phoenix-Tucson AQCR -- Mobile Source HC Inventory (Determined Using Anticipated Normal Growth Rates from Table 9-7)

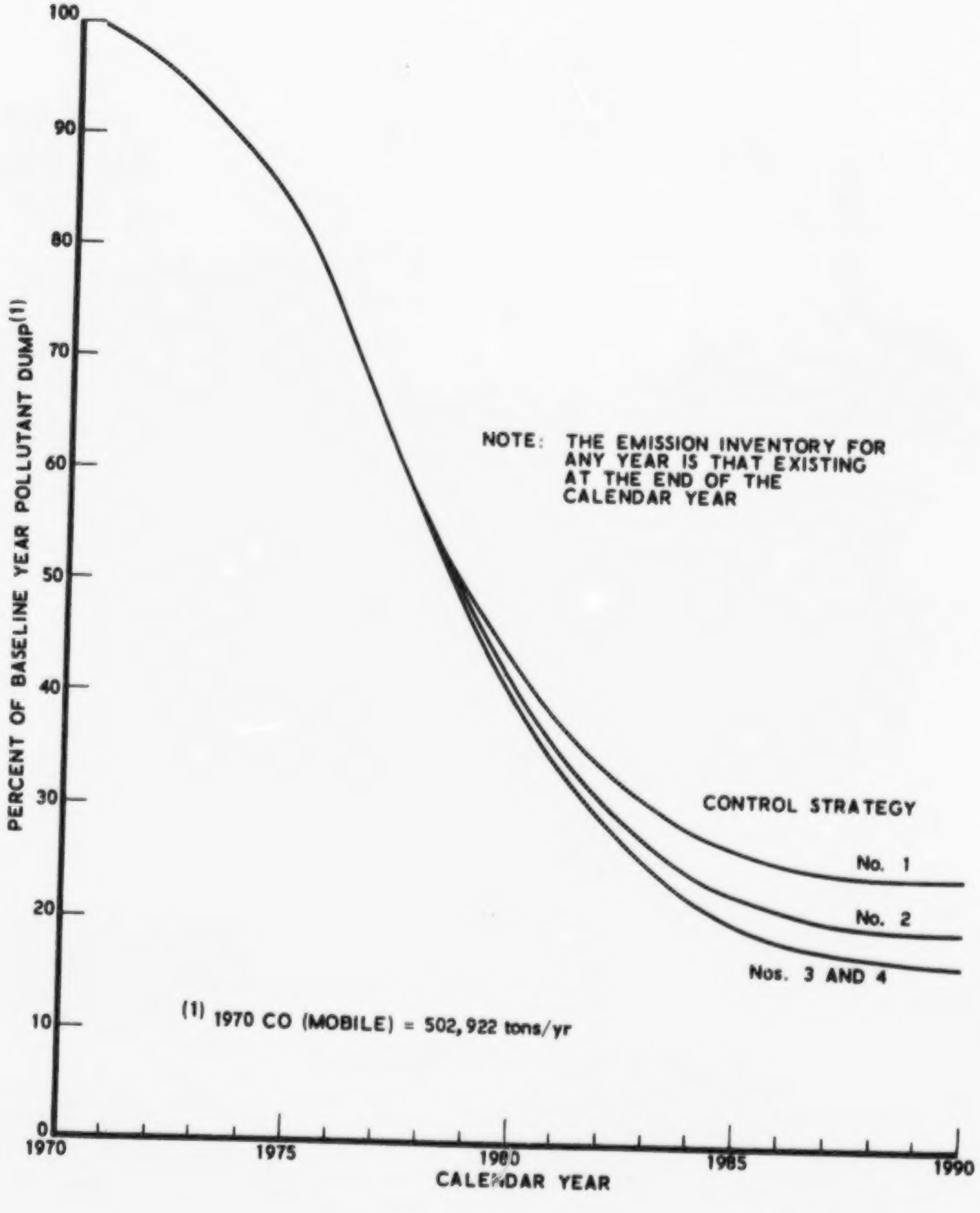

Figure 9-17. Phoenix-Tucson AQCR -- Mobile Source CO Inventory (Determined Using Anticipated Growth Rates from Table 9-7)

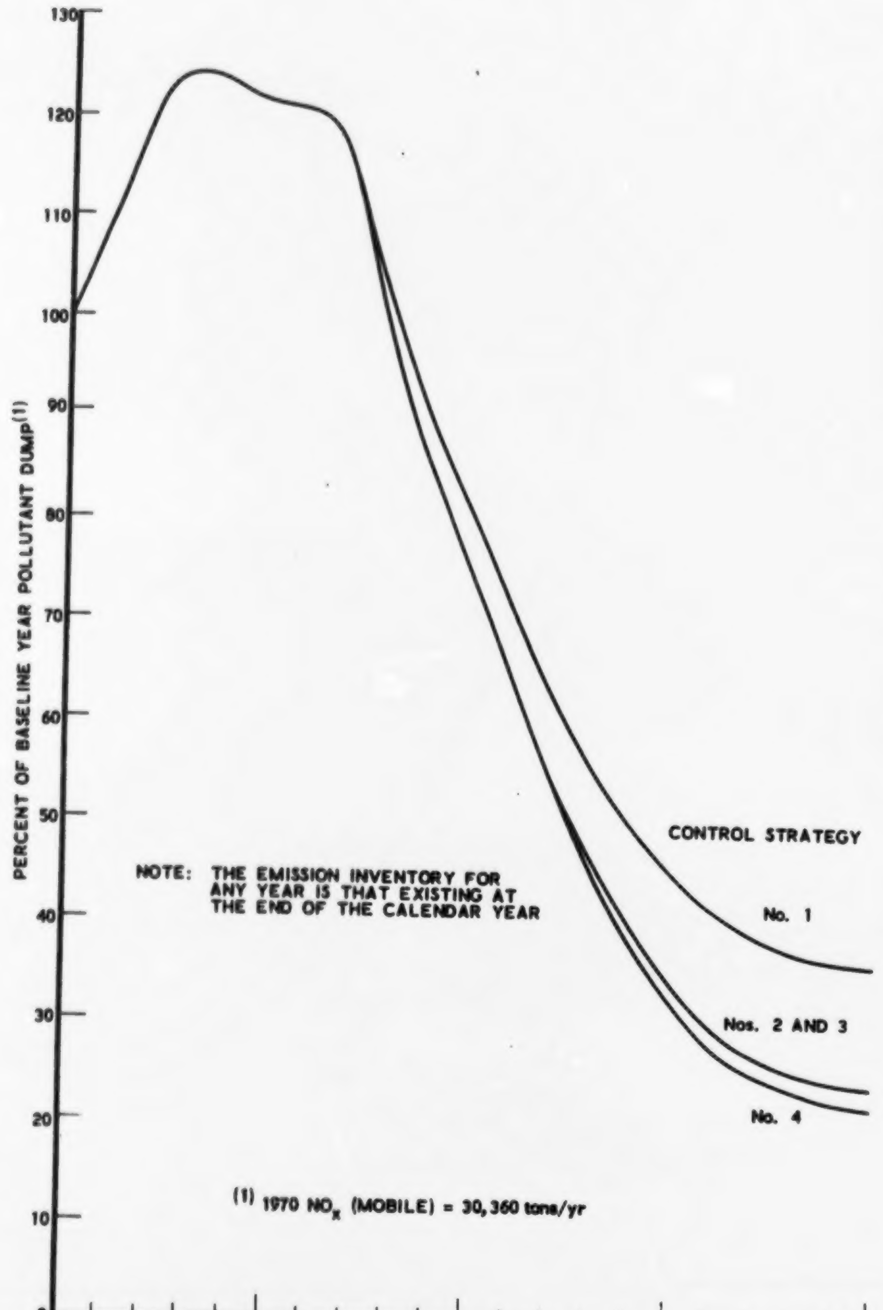

Figure 9-18. Phoenix-Tucson AQCR -- Mobile Source NO$_x$ Inventory (Determined Using Anticipated Normal Growth Rates from Table 9-7)

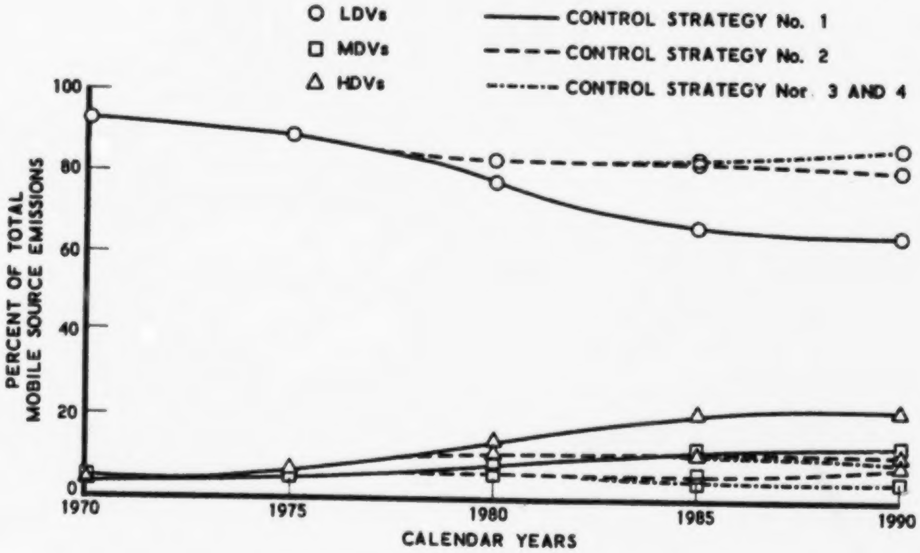

Figure 9-19. Phoenix-Tucson AQCR -- HC Percentage Contribution of Vehicle Classes (Normal Growth Rates from Table 9-7)

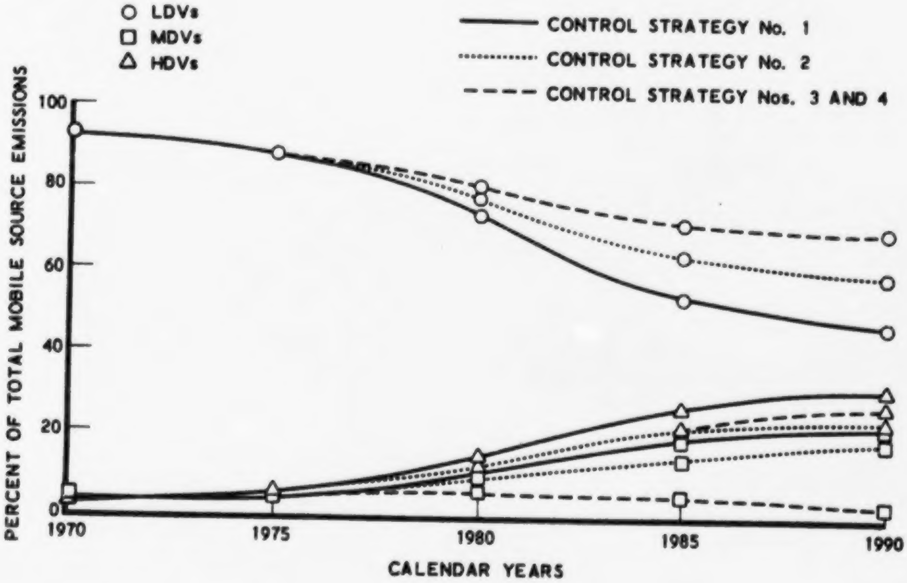

Figure 9-20. Phoenix-Tucson AQCR -- CO Percentage Contribution of Vehicle Classes (Normal Growth Rates from Table 9-7)

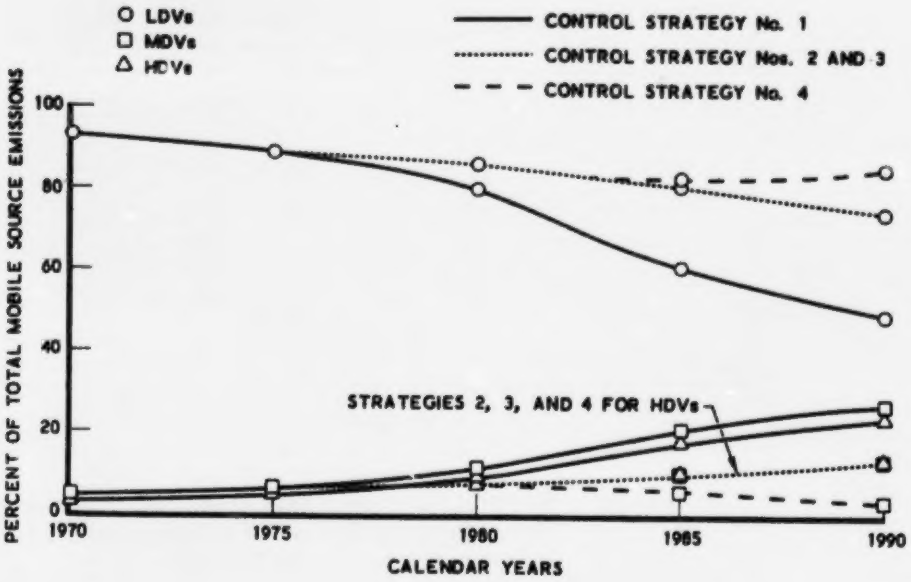

Figure 9-21. Phoenix-Tucson AQCR -- NO_x Percentage Contribution of Vehicle Classes (Normal Growth Rates from Table 9-7)

REFERENCES

9-1. D. S. Kircher and D. P. Armstrong, An Interim Report on Motor Vehicle Emission Estimation, EPA (October 1972).

9-2. Private communication with D. S. Kircher, EPA (July 1973).

9-3. Private communication with Curtis E. Fett, EPA/DECT (July 1973).

9-4. Private communication with J. H. Somers, EPA/DECT (July 1973).

9-5. Statistical Abstract of the United States, 1972, U. S. Department of Commerce, Bureau of the Census

SECTION 10

APPENDIXES

A. SIGNIFICANT VISITS OR COMMUNICATIONS

B. MEDIUM-DUTY BASELINE EMISSIONS TEST DATA

C. MEDIUM-DUTY VEHICLES TESTED AT EPA AND EXHAUST EMISSION TEST RESULTS

D. DRIVING CYCLE DATA

E. EMISSION INVENTORY CALCULATIONS

APPENDIX A

SIGNIFICANT VISITS OR COMMUNICATIONS

Date	Company/Agency Name	Personnel Contacted
22 May 1973	The Calspan Corporation (meeting with subsequent telecons)	L. Bogdan, Principal Research Engineer A.F. Burke, Principal Research Engineer H.G. Reif, Principal Economist C. Groenewald, Operations Research Department
23 May 1973	Tri-State Regional Planning Commission, New York City (meeting with subsequent telecon)	E. R. Lozada, Data Services N. Lucey, Highway Planning R. Leighton, Truck Operations
June 1973 and July 1973	Southwest Research Institute (San Antonio, Texas) (several telecons and letter replies)	Karl J. Springer Melvin N. Ingalls
23 May 1973	EPA/Monitoring and Data Analysis Division (meeting with subsequent telecons)	EPA/Durham, N.C. Personnel Herschel Slater Eric Finke David Kircher Roger Morris EPA/Ann Arbor, Michigan Personnel Dr. Jose L. Bascunana Dr. Joseph H. Somers Tom Comfort
12 June 1973	New York State Department of Air Resources	D. Gower, Surveillance T. Davis, Abatement Planning Bureau

Date	Company/Agency Name	Personnel Contacted
June - July 1973	New York City Department of Air Resources	Bureau of Technical Services Personnel Dr. Edward Ferrand John Sontowski Michael Walsh Fred Masciello
13 June 1973	General Electric Corp., Philadelphia, Pa.	L. Dworetsky, Chief Engineer for Environmental Monitoring
25 July 1973	Riverside County Air Pollution Control District	G.R. Kinley, Air Pollution Control Officer
5 June 1973 30 July 1973	Los Angeles County Air Pollution Control District (meetings and subsequent telecons)	Los Angeles APCD Personnel W.J. Hamming, Chief Air Pollution Analyst J.E. Dickinson, Asst. Chief Air Pollution Analyst R.N. Keith, Senior Meteorologist A. Davidson, Meteorologist J. Foon, Analyst
24 August 1973	San Diego County Air Pollution Control District (telecon)	B.R. McEntire
27 August 1973	Los Angeles Department of Water and Power (telecon)	N. Bassin

APPENDIX B

MEDIUM-DUTY BASELINE EMISSIONS TEST DATA

Table B-1. Medium-Duty Vehicle Baseline Emission Test Data

Tested By	Truck Number	Year	Make	Model	Body Type	GVW, lb	GCW, lb	Inertia Test Wt, lb	Engine		Average Emissions, gm/mi				Number of Tests	Engine Tuned?
									CID	Cyl	HC	CO	CO_2	NO_x		
EPA/DFCT	1	72	Chev	C-20	Pickup	7,500	4385	5000	350	8	3.14	19.32	875.88	4.88	2	No
	2	66	Dodge	D-100	Pickup	5,200	3620	4000	225	6	3.55	49.92	591.11	5.70	2	No
	3	71	AMC	J4000	Pickup	7,000	4265	5500	360	8	6.05	24.44	945.76	7.66	2	No
	4	68	Dodge	B300	Van	7,700	5565	6500	318	8	5.52	56.02	697.69	9.43	2	No
	5	71	IHC	- -	Multi-Stop	6,100	4295	5000	232	6	4.02	65.18	698.50	5.63	2	No
	6	72	Ford	F-350	Van	10,000	6620	7500	300	6	2.89	43.67	955.35	10.77	2	No
	7	72	Chev	P-35	Van	10,000	6762	7500	350	8	3.86	65.46	1144.03	9.32	2	No
	8	72	Ford	F-300	Van	6,050	4110	4500	240	6	2.76	28.78	682.94	5.40	2	No
	9	72	Dodge	D-300	Pickup	9,000	5185	6000	400	8	3.58	57.44	851.52	5.91	2	No
	10	70	Dodge	- -	Motor Home	10,000	8645	9000	318	8	9.32	158.98	1082.03	14.85	4	No
	11	72	Chev	C-35	Stake	10,000	5395	7500	350	8	2.43	29.82	1240.35	9.02	2	No
	12	72	Ford	F-250	Pickup	6,900	4460	5000	360	8	4.43	26.46	842.57	12.63	4	No
	13	71	Dodge	D-300	NA	10,000	5575	6000	318	8	4.83	58.52	952.37	9.99	4	No
	14	69	Ford	F-300	Van	6,800	4170	4500	240	6	6.87	14.65	560.63	5.38	2	No
	15	71	Chev	C-30	NA	10,000	5580	6000	350	8	6.13	79.32	767.81	9.45	4	No
	16	70	Ford	E-300	Van	6,500	4235	4500	240	6	4.55	39.32	627.09	6.67	4	No
	17	67	Ford	F-350	NA	10,000	6630	7000	300	6	6.48	65.75	872.67	15.97	2	No
	18	72	Chev	C-20	Pickup	10,000	6770	7500	350	8	5.32	47.26	976.68	12.04	4	No
	19	72	Ford	F-250	Pickup	6,900	4120	4500	300	6	2.50	29.57	631.80	10.95	4	No
	20	71	Chev	C-30	Van	10,000	6820	7500	350	8	5.19	61.39	1058.20	12.44	4	No
	21	69	GMC	Sierra Grande	Pickup	7,500	4730	5000	396	8	6.95	83.64	734.11	7.03	2	No

Table B-1. Medium-Duty Vehicle Baseline Emission Test Data (Continued)

Tested By	Truck Number	Year	Make	Model	Body Type	GVW, lb	GCW, lb	Inertia Test Wt, lb	Engine		Average Emissions, gm/mi				Number of Tests	Engine Tuned?
									CID	Cyl	HC	CO	CO_2	NO_x		
EPA/DECT	22	71	Chev	C-20	Pickup	6,200	4920	5500	350	8	5.97	37.05	757.78	8.56	2	No
	23	65	Chev	C-20	Pickup	7,500	4325	5000	250	6	7.69	70.49	532.08	8.99	2	No
	24	69	Ford	F-250	Motor Home	6,100	6315	7000	360	8	8.06	116.06	934.45	15.82	3	No
	25	71	Ford	E-300	Van	7,600	5840	6500	302	8	9.35	59.00	786.11	15.55	2	No
	26	71	Ford	E-300	Van	6,050	4340	5000	302	8	6.94	73.95	695.26	6.58	2	No
	27	68	Ford	F-250	Pickup	7,500	4620	5000	240	6	8.49	94.47	569.85	6.53	2	No
	28	70	Chev	C-20	Pickup	7,500	4900	5500	350	8	4.97	36.06	801.89	12.77	2	No
	29	70	Ford	F-250	Camper	6,900	7150	5500	360	8	5.65	78.05	790.79	10.19	2	No
	30	66	Chev	C-20	Pickup	7,500	4405	5000	283	8	13.00	114.47	609.73	6.33	2	No
	31	68	GMC	C-25	NA	7,500	5125	5500	327	8	7.65	99.21	735.49	10.75	2	No
	32	72	Dodge	B-300	Van	7,000	4160	4500	360	8	3.91	31.01	734.86	7.60	2	No
	33	66	Chev	C-20	Pickup	7,500	4500	5000	250	6	9.86	65.94	699.98	13.19	2	No
	34	71	Ford	NA	Camper	6,900	4920	5500	360	8	8.17	111.56	670.72	7.01	2	No
	35	71	Chev	C-30	Camper	9,000	4198	4500	400	8	4.10	43.82	910.68	11.01	3	No
	36	69	Ford	F-250	Pickup	6,900	4600	5000	360	8	12.45	106.61	710.96	6.94	2	No
	37	72	Ford	F-250	Pickup	8,100	4675	5000	360	8	6.35	75.28	728.02	7.97	4	No
	38	65	Chev	C-20	Pickup	7,500	4650	5000	283	8	- -	- -	-	- -	1	No
	39	71	Ford	F-250	Pickup	7,500	5100	5500	360	8	8.06	98.39	760.73	5.67	2	No
	40	71	Chev	C-20	Pickup	6,400	4880	5000	307	8	6.41	38.78	737.17	10.06	2	No
	41	71	Chev	C-20	Camper	6,700	4600	5000	350	8	4.06	78.23	713.24	6.12	2	No
	42	71	Chev	C-20	Pickup	6,400	4275	4500	307	8	4.21	41.72	690.36	7.80	4	No
	43	72	Ford	F-250	Pickup	7,800	4715	5000	390	8	3.38	38.76	794.52	10.14	4	No

Table B-1. Medium-Duty Vehicle Baseline Emission Test Data (Continued)

Tested By	Truck Number	Year	Make	Model	Body Type	GVW, lb	GCW, lb	Inertia Test Wt, lb	Engine		Average Emissions, gm/mi				Number of Tests	Engine Tuned?
									CID	Cyl	HC	CO	CO_2	NO_x		
EPA/DECT	44	--	Chev	C-30	--	--	--	--	--	--	--	--	--	--	--	--
	45	--	Chev	C-30	--	--	--	--	--	--	--	--	--	--	--	--
	46	--	Chev	C-20	--	--	--	--	--	--	--	--	--	--	--	--
	47	72	Ford	F-700	NA	23,500	8950	10,000	361	8	6.01	75.80	1185.69	16.38	2	No
	48	72	Chev	C-20	Pickup	6,200	4540	5000	350	8	3.20	24.19	684.49	7.03	2	Yes
	49	72	Ford	F-250	Pickup	7,500	4495	5500	250	6	5.23	32.49	737.25	2.78[a]	2	Yes
	50	70	GMC	C-35	NA	14,000	8180	10,000	350	8	6.85	86.66	966.76	13.02	2	No
	51	69	Chev	C-20	Pickup	7,500	4540	5500	350	8	9.70	152.15	639.87	5.48	2	No
	52	70	GMC	C-35	NA	14,000	8175	10,000	350	8	7.53	83.61	986.91	13.01	2	No
	53	72	Dodge	D-300	NA	10,000	5200	6500	318	8	4.61	21.41	806.88	8.80	2	Yes
	54	71	Ford	F-350	Van	10,000	7320	8500	300	6	6.64	119.87	759.81	9.01	2	No
	55	69	Chev	C-20	Pickup	7,500	4540	5000	307	8	6.20	31.39	641.15	7.22	2	No
	56[b]	73	Chev	Camper Special	--	9,000	5170	6500	350	8	1.63	28.96	1000.18	5.87	2	Yes
	57[b]	73	Chev	C-20	Pickup	8,200	5545	7000	454	8	1.68	11.07	998.32	10.53	2	Yes
	58	69	Chev	C-20	Dump-Bed	10,000	--	7500	350	8	8.18	94.33	759.31	8.54	1	No
	59	73	Ford	F-250	Pickup	6,200	--	5000	360	8	3.51	50.60	760.87	4.67	2	Yes
	60	73	Chev	C-20	Pickup	6,400	--	5500	454	8	1.58	31.18	1091.85	4.69	2	Yes
	61[b]	73	Chev	C-20	Pickup	6,800	--	5500	350	8	2.03	12.47	829.63	6.62	2	Yes
	62[b]	73	Chev	C-20	Pickup	6,400	--	5000	250	6	3.30	33.47	710.89	3.68	2	Yes
	63[b, c]	73	Chev	C-20	Pickup	6,400	--	5000	292	6	3.21	57.59	1041.36	2.50	2	No
	63[b, c]	(Tuned)									1.28	31.70	740.60	2.32	2	Yes
	64	73	BIC	1510	Chassis	14,000	--	8000	345	8	6.79	67.43	931.81	4.59	2	Yes

Table B-1. Medium-Duty Vehicle Baseline Emission Test Data (Continued)

Tested By	Truck Number	Year	Make	Model	Body Type	GVW, lb	GCW, lb	Inertia Test Wt, lb	Engine		Average Emissions, gm/mi				Number of Tests	Engine Tuned?
									CID	Cyl	HC	CO	CO_2	NO_x		
EPA/DECT	65	73	Chev	P-30	Std. Van	8,200	--	7000	350	8	2.52	40.51	968.25	7.18	2	Yes
	66[b]	73	Chev	P-30	Barth Motor Home	11,000	--	8500	454	8	3.61	51.91	1202.20	9.85	2	Yes
	67	73	Ford	F-250	Pickup	6,200	--	5000	360	8	3.91	31.43	763.70	5.73	2	Yes
SWRI	200	70	Ford	F-250	Pickup	7,500	4020	5000	240	6	9.69	139.06	502.33	5.93	2	No
	201	69	Chev	C-20	Pickup	7,500	4430	5500	292	6	6.18	68.39	508.11	4.81	2	No
	202	66	Chev	C-20	Pickup	7,500	4260	5500	327	8	39.07	122.61	648.45	4.88	2	No
	203	68	Chev	C-20	Pickup	7,500	4390	5500	327	8	19.70	236.05	532.02	2.75	2	No
	204	71	Chev	C-20	Pickup	7,500	4400	5000	350	8	3.48	24.20	717.08	6.82	2	No
	205	73	Dodge	NA	Motor Home	11,000	7730	8000	318	8	8.97	126.39	1008.05	12.88	2	Yes
	206	71	IHC	1210	Pickup	6,100	4450	5000	345	8	6.02	64.91	617.20	4.13	2	No
	207	66	IHC	Metro Van-1200	Panel	8,000	5900	7000	266	6	18.50	170.41	702.84	5.56	2	No
	208	72	IHC	1210	Pickup	7,500	4710	5500	304	8	4.72	41.37	677.79	8.47	2	No
	208	(Tuned)									4.35	59.76	734.00	5.14	2	Yes
	209	73	Ford	E-300	Van	7,000	4260	5500	302	8	5.82	38.40	629.83	4.73	2	No
	209	(Tuned)									5.30	31.87	706.37	3.80	2	Yes
	210	70	Chev	C-30	Pickup	8,000	4990	6000	292	6	7.11	76.53	655.10	7.21	2	No
	211	70	Chev	C-20	Pickup	6,200	5990	6500	250	6	6.35	91.58	659.79	8.40	2	No
	212	70	Dodge	D-200	Pickup	7,500	4300	5500	318	8	5.59	37.40	604.05	5.29	2	No
	213	72	Ford	E-300	Van	7,000	4450	5500	302	8	4.24	68.51	774.11	4.13	2	Yes

Table B-1. Medium-Duty Vehicle Baseline Emission Test Data (Continued)

Tested By	Truck Number	Year	Make	Model	Body Type	GVW, lb	GCW, lb	Inertia Test Wt, lb	Engine		Average Emissions, gm/mi				Number of Tests	Engine Tuned?
									CID	Cyl	HC	CO	CO_2	NO_x		
SWRI	214	72	Ford	E-300	Van	7,000	4080	5000	302	8	5.84	40.75	628.82	3.53	2	Yes
	215	70	GMC	C-25	Pickup	6,200	4360	5000	292	6	5.86	53.20	593.33	7.37	2	No
	216	69	Dodge	D-27	Motor Home	12,000	9820	11,000	318	8	6.02	88.72	757.98	6.34	2	No
	217	73	Chev	C-20	Pickup	6,400	4900	5500	454	8	5.13	70.52	860.91	4.26	2	Yes
	218	72	Chev	C-20	Pickup	6,200	4340	5000	350	8	5.34	40.52	634.38	4.97	2	No
	218	(Tuned)									7.01	49.46	636.89	4.82	2	Yes
	219	73	Chev	C-30	Van	6,400	4040	5000	350	8	5.23	45.10	820.52	4.04	2	Yes
	220	70	Ford	F-350	Stake	10,000	6000	7500	300	6	4.01	72.78	855.51	11.45	2	No
	221	72	Ford	E-300	Motor Home	8,300	6580	7500	302	8	5.55	72.23	818.19	7.26	2	Yes
	222	72	Dodge	C-300	Stake	10,000	5350	7500	318	8	8.24	77.66	846.14	6.77	2	No
	222	(Tuned)									8.00	79.97	793.44	5.13	2	Yes
	223	72	GMC	C-35	Wrecker	9,000	5590	7500	350	8	9.95	82.11	523.44	7.03	2	Yes
	224	70	Ford	F-250	Pickup	6,100	5000	5500	360	8	9.90	126.58	855.21	4.00	2	No
	225	67	Ford	F-250	Pickup	6,100	5100	6000	240	6	10.23	146.27	707.96	2.66	2	No
AESI	226	67	Ford	F-250	Pickup	6,100	5100	6000	240	6	13.42	145.05	719.13	2.30	2	No
	227	72	IHC	1210	Travellal	7,500	5380	6500	345	8	5.22	67.33	613.69	5.98	2	Yes
	228	72	Chev	C-20	Pickup	6,200	4800	5500	350	8	3.19	56.82	527.89	7.46	2	Yes
	229	67	IHC	1200	Crew Cab Pickup	7,300	4820	6000	241	6	13.68	128.98	844.30	3.50	2	No
	230	67	Chev	C-20	Pickup	7,500	6000	6500	250	6	12.16	118.45	611.02	6.00	2	No
	231	65	Ford	F-350	Platform	10,000	7120	8200	240	6	20.95	182.82	630.96	5.27	2	No

Table B-1. Medium-Duty Vehicle Baseline Emission Test Data (Concluded)

Tested By	Truck Number	Year	Make	Model	Body Type	GVW, lb	GCW, lb	Inertia Test Wt, lb	Engine		Average Emissions, gm/mi				Number of Tests	Engine Tuned?
									CID	Cyl	HC	CO	CO_2	NO_x		
AESI	232	71	Ford	F-350	Platform	10,000	7210	8200	360	8	12.85	116.28	749.96	6.93	2	No
	233	68	Chev	C-20	Pickup	7,500	4190	5000	307	8	11.00	135.10	492.41	1.22	2	No
	234	68	Ford	F-250	Pickup	7,500	4490	5500	240	6	7.56	78.97	477.71	5.67	2	No
	235	72	GMC	P-35	Van	7,800	6960	7500	292	6	5.31	79.61	788.42	7.22	2	Yes
	236	66	Ford	F-250	Pickup	7,500	5100	6000	240	6	10.97	140.30	519.29	1.78	2	No
	237	69	Ford	F-250	Pickup	6,100	4500	5000	360	8	8.04	103.50	582.09	2.81	2	No
	238	73	Ford	E-300	Econo Panel Pickup	8,100	5340	5500	302	8	6.21	87.22	566.46	5.69	2	Yes
	239	71	Chev	C-20	Pickup	6,200	4500	5000	350	8	5.63	50.27	656.20	5.01	2	No
	240	73	IHC	1310	Pickup	10,000	--	7500	304	8	10.88	131.80	859.84	3.16	2	Yes
	241	72	Ford	F-250	Pickup	6,900		6000	300	6	6.30	112.03	737.09	8.12	2	Yes
	242	--	--	--	--		--	--	--					--	--	--
	243	72	Winnebago	D22	Motor Home	13,000	--	8500	413	8	13.96	139.45	1131.14	14.92	2	Yes
	244	--	--		--			--	--		--				--	--
	245	72	Champion	(Dodge)	Motor Home	11,000	--	8500	318	8	8.23	141.49	990.24	11.96	2	Yes

[a] Exhaust Gas Recirculation System

[b] Green Engine

[c] Start of More Extensive Tuneup Checks

APPENDIX C

MEDIUM-DUTY VEHICLES TESTED AT EPA AND EXHAUST EMISSION TEST RESULTS

Table C-1. Medium-Duty Vehicles Tested at EPA in June, July, and August 1972 (Ref 3-4)

Vehicle Number, Make, and Type	Description	Percent Load	Inertia Test Weight, lb	1975 Federal Test Procedure Emissions, gm/mi		
				HC	CO	NO_x
1 Chev. Cheyenne 3/4-ton pickup	CID = 350 V-8 Automatic transmission GVW = 7,500 lb GCW = 4,385 lb Mileage = 5704	0	4,500	3.08	20.51	5.05
		25	5,000	3.14	19.32	4.88
		50	6,000	3.25	20.20	5.80
		100	7,500	3.49	26.37	7.32
2 Dodge Custom 100 Light Pickup	CID = 225 6 Automatic transmission GVW = 5,240 lb GCW = 3,920 lb Mileage = 1962	0	3,500	3.35	65.27	5.33
		25	4,000	3.05	49.92	5.70
		50	4,500	3.81	73.16	5.19
		100	5,000	3.73	83.95	5.09
3 Jeep Model 400E Pickup	CID = 360 V-8 4-speed manual transmission GVW = 7,000 lb GCW = 4,295 lb Mileage = 774	0	4,500	5.34	19.54	6.09
		25	5,000	6.36	27.09	6.77
		50	5,500	6.05	24.44	7.66
		100	7,000	6.01	29.45	8.00
4 Dodge Tradesman 300 Van	CID = 318 V-8 Automatic transmission GVW = 7,700 lb GCW = 5,565 lb Mileage = 4152	0	6,000	5.42	48.13	9.46
		25	6,000	5.32	46.65	9.65
		50	6,500	5.52	56.02	9.43
		100	7,500	5.69	64.84	9.29

Table C-1. Medium-Duty Vehicles Tested at EPA in June, July, and August 1972 (Ref. 3-4) (Continued)

Vehicle Number, Make, and Type	Description	Percent Load	Inertia Test Weight, lb	1975 Federal Test Procedure Emissions, gm/mi		
				HC	CO	NO$_x$
5 IHC Model DM106 Light Van	CID = 232 6 3-speed manual transmission GVW = 6, 100 lb GCW = 4, 295 lb Mileage = 623	0	4, 500	4. 02	72. 17	5. 61
		25	4, 500	3. 52	60. 07	5. 26
		50	5, 000	4. 02	65. 18	5. 63
		100	6, 000	5. 59	95. 43	5. 95
6 Ford 350 Box Van	CID = 300 6 Automatic transmission GVW = 10, 000 lb GCW = 6, 220 lb Mileage = 41, 520	0	7, 000	2. 70	28. 72	11. 48
		25	7, 500	2. 89	43. 07	10. 77
		50	8, 000	3. 05	57. 76	11. 89
		100	10, 000	3. 75	75. 33	11. 62
7 Chev, Custom 30 Box Van	CID = 350 V-8 Automatic transmission GVW = 10, 000 lb GCW = 6, 750 lb Mileage = 497	0	7, 000	3. 87	61. 88	9. 39
		25	7, 500	3. 86	65. 46	9. 32
		50	8, 500	4. 06	67. 22	11. 06
		100	10, 000	5. 05	76. 61	11. 76
8 Ford Econoline Van	CID = 240 6 Automatic transmission GVW = 6, 050 lb GCW = 4, 110 lb Mileage = 503	0	4, 500			
		25	4, 500	2. 76	28. 78	5. 40
		50	5, 000	2. 93	33. 42	5. 34
		100	6, 000	3. 34	48. 19	6. 45

Table C-1. Medium-Duty Vehicles Tested at EPA in June, July, and Auguts 1972 (Ref. 3-4) (Concluded)

Vehicle Number, Make, and Type	Description	Percent Load	Inertia Test Weight, lb	1975 Federal Test Procedure Emissions, gm/mi		
				HC	CO	NO_x
9 Dodge Crew Cab Pickup	CID = 400 Automatic transmission GVW = 9,000 lb GCW = 5,185 lb Mileage = 2262	0	5,500	3.68	55.07	6.56
		25	6,000	3.58	57.44	5.91
		50	7,000	3.39	60.42	6.32
		100	9,000	4.57	85.79	7.74
11 Chev. Stake Truck	CID = 350 Automatic transmission GVW = 10,000 lb GCW = 5,395 lb Mileage = 1183	0	5,500	2.42	18.44	7.89
		25	6,500	2.38	24.13	8.30
		50	7,500	2.43	29.82	9.02
		100	10,000	3.91	60.68	9.87

Table C-2. Exhaust Emission Test Results at Various Inertia Weights and Road Horsepower Settings -- Trucks 246 and 250 (Ref. 3-4)

Truck 246 -- 1972 Winnebago

Run Number	Inertia Test Weight, lb	1975 Federal Test Procedure Emissions, gm/mi		
		HC	CO	NO_x
3	7,900	5.71	69.08	9.27
4	7,900	6.63	91.66	10.54
5	8,900	7.35	103.30	10.14
6	9,600	6.75	101.65	12.01
7	11,200	7.18	109.08	10.52
8	11,200	7.29	107.29	10.77

Truck 250 -- 1972 Chevrolet Box Van

Run Number	Inertia Test Weight, lb	1975 Federal Test Procedure Emissions, gm/mi		
		HC	CO	NO_x
1	7,500	7.52	110.45	7.14
2	8,500	7.33	133.82	7.59
3	9,600	9.75	180.69	7.58

APPENDIX D

DRIVING CYCLE DATA

Driving Cycles for Emission Comparisons

Ethyl Corporation Chassis Dynamometer Cycles

Map of San Antonio Road Route

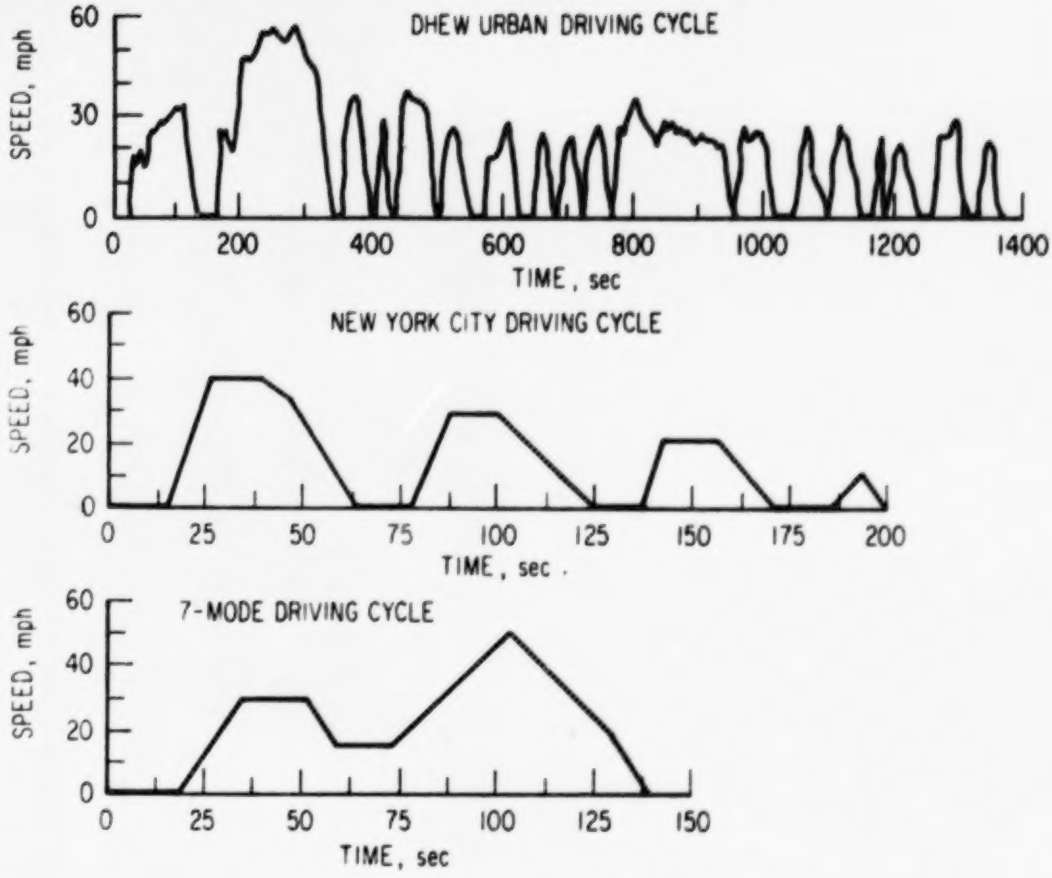

Figure D-1. Driving Cycles for Emission Comparisons (Ref. 3-10)

Table D-1. Ethyl Corporation Chassis Dynamometer Cycles (Ref. 3-7)

DLA-1 -- Group II Median Truck (6,000 to 10,000-lb GVW)

Mode	Rear Wheel Speed, mph	Duration, sec
1. Idle	0	22
2. Gear-1	0 to 16	6
3. Gear-2	15 to 27	5
4. Gear-3	26 to 32	8
5. Decelerate	32 to 27	6
6. Accelerate	27 to 32	5
7. Decelerate	32 to 20	5
8. Accelerate	20 to 29	6
9. Cruise	29	22
10. Decelerate	29 to 19	9
11. Accelerate	19 to 29	5
12. Decelerate	29 to 0	15

DLA-2 -- Group III Median Truck (10,000 to 19,500-lb GVW)

Mode	Rear Wheel Speed, mph	Duration, sec
1. Idle	0	20
2. Gear-2	0 to 10	3
3. Gear-3	9 to 21	10
4. Gear-4	20 to 26	6
5. Gear-5	24 to 35	12
6. Decelerate	35 to 25	10
7. Cruise	25	12
8. Accelerate	25 to 28	6
9. Cruise	28	12
10. Decelerate	28 to 0	15

DLA-3 -- Group IV Median Truck (over 19,500-lb GVW)

Mode	Rear Wheel Speed, mph	Duration, sec
1. Idle	0	27
2. Gear-2	0 to 12	9
3. Gear-3	10 to 21	9
4. Gear-4	18 to 32	9
5. Gear-5	28 to 35	12
6. Decelerate	35 to 21	13
7. Cruise	21	28
8. Accelerate	21 to 24	19
9. Cruise	24	28
10. Decelerate	24 to 21	6
11. Cruise	21	28
12. Decelerate	21 to 0	12

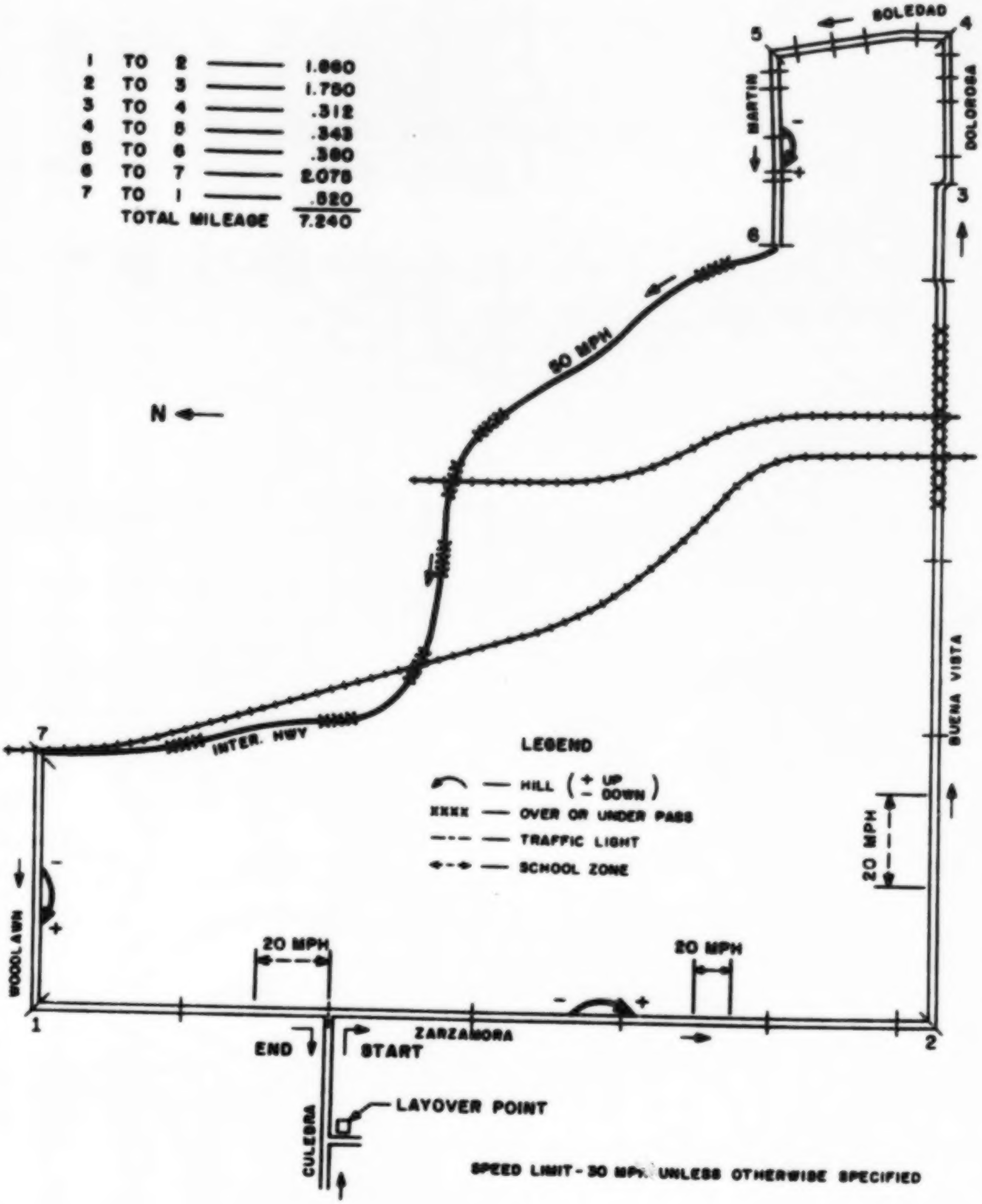
1 TO 2 1.860
2 TO 3 1.750
3 TO 4 .312
4 TO 5 .343
5 TO 6 .380
6 TO 7 2.075
7 TO 1 .520
TOTAL MILEAGE 7.240
N
SOLEDAD
MARTIN
DOLOROSA
50 MPH
INTER. HWY
BUENA VISTA
LEGEND
HILL (+ UP − DOWN)
XXXX — OVER OR UNDER PASS
TRAFFIC LIGHT
SCHOOL ZONE
20 MPH
WOODLAWN
ZARZAMORA
END
START
LAYOVER POINT
CULEBRA
SPEED LIMIT - 30 MPH UNLESS OTHERWISE SPECIFIED
1
2
3
4
5
6
7

Figure D-2. San Antonio Heavy-Duty Gasoline Truck Road Route (Ref. 3-8)

APPENDIX E

EMISSION INVENTORY CALCULATIONS

Mobile source pollutant emission inventories (HC, CO, and NO_x) for the LDV, MDV, and HDV classes were presented in Section 9 to illustrate the effect of four different MDV emission control level strategies on overall HC, CO, and NO_x emissions in the New York City, Los Angeles, and Phoenix-Tucson AQCRs.

The results were shown, for each pollutant, as the fraction or percentage of the 1970 emission inventory for the AQCR of interest, for the years 1970 through 1990. The emission inventory for any year (e. g., 1975) is based on the full calendar year (e. g., from 1 January to 31 December 1975). Examination of available sales data indicates that approximately one-third of the sales of a given model year (e. g., 1976) occurs during the period September through December of the prior calendar year. Therefore, the emission calculations for a given year (e. g., 1975) include the effects of one-third of the sales of the next (1976) model year.

This section is supplementary to Section 9 and presents a brief discussion of the calculational technique used.

The approach used to calculate vehicle emissions was, in general, similar to the method recommended by EPA in Ref. E-1. The calculation was made independently for each of four vehicle classes (passenger cars, light-duty trucks, MDVs, and HDVs) at each of a series of discrete years to project the trend of vehicle emissions from 1970 to 1990. The results for passenger cars and light-duty trucks were combined as LDVs.

Four different sets of exhaust emission alternative standards for MDVs and two for HDVs were examined. They were combined to represent four possible emission control strategies. These exhaust emission levels are shown in Tables 9-3, 9-4, 9-5, and 9-6. In all four strategies, the LDV emission standards (or characteristic levels) for passenger cars and light-duty trucks are invariant as shown in Table 9-1 and Ref. 9-1.

In Strategy No. I, both MDV and HDV emission levels remain at 1974 levels indefinitely.

In Stragegy No. II, both MDV and HDV emissions are reduced to reflect compliance with California 1975 HDV engine emission standards. Both changes occur in California in 1975 and the rest of the United States in 1977.

Strategy No. III is the same as Strategy No. II except that MDV emissions are further reduced in California in 1977 and the rest of the United States in 1979. These reductions are based on the use of an oxidation catalyst plus EGR.

Strategy No. IV is similar to Strategy No. III except that MDV NO_x emissions are further reduced in California in 1980 and in 1982 for the rest of the United States. It is assumed that the incorporation of a reducing catalyst (or other equivalent) permits the attainment of these ultralow NO_x emission values.

For each vehicle class (passenger car, light-duty truck, MDV, and HDV) and for each calendar year, the principal calculational variables were:

a. The number of vehicles registered for each model year
b. The mileage of vehicles according to age
c. The specific vehicle pollutant emission levels for each model year

E. 1 NUMBER OF VEHICLES REGISTERED

The calculation of the number of vehicles registered as a function of model year was based on two main factors: the number of vehicles registered when new and the loss of vehicles resulting from age (attrition).

E. 1. 1 New Vehicle Registrations

The number of new motor vehicles historically registered each year was determined from published values in the Automotive News for the two basic classes, passenger cars and trucks. The proportional split of trucks into the LDV, MDV, and HDV weight classes was based on 1972 truck registration surveys for the AQCRs of interest (discussed in Section 8).

Future trends in new motor vehicle sales (both passenger cars and trucks) were established by adjusting sales growth by the "above 18"[1] population growth trend as obtained from census projections (Ref. E-2). In addition, for passenger car registration projections, a standard-of-living increase factor was included. The new vehicle growth factors determined by this approach are shown in Table 9-7 as "anticipated" growth factors. In the case of the New York City AQCR, a high growth rate of 4 percent per year was also arbitrarily assumed in order to examine the impact of growth rate assumptions on resulting mobile source emission inventories.

Initially, a new vehicle registration growth rate based on historical total registration data trends was derived; however, using these past values for projected growth rates led to absurd truck-to-passenger-car ratios in projecting to the 1990's. This was the principal reason for adopting vehicle growth factors that were related to population forecasts.

The calculational procedure is capable of applying the vehicle growth factor to either the whole class of vehicles under examination or to only the new vehicles each year. Correlations have indicated that applying the growth factor to new vehicle sales only is more reasonable. Over the long range of forecasting, this technique predicts a reduced rate of increase in vehicle sales over the very high vehicle sales growth values of recent years.

In the case of passenger cars, in addition to the growth rate in new car sales based on population growth, a factor reflecting an increase in the specific car-per-person ratio was added, reflecting the present trends of multiple cars per family ownership. The present car-per-person-above-18 ratio is about 70 percent. Because of factors such as illness, blindness, and old age, a car-per-person-above-18 ratio of 90 percent appears to be a probable upper limit. An intermediate value of 80 percent was adopted in the present study as a most probable forecast increase.

---

[1] Above 18 years of age

E. 1. 2 Vehicle Attrition Factor

An attrition factor resulting from age was used to represent the percentage of vehicles remaining in service as a function of vehicle age. The age distribution of vehicles obtained from R. L. Polk Company registration data was insufficient to establish uniform profiles for each AQCR; therefore, a mathematical model of the following form was used.

$$y = e^{-C_1X^N} + e^{C_2(25 - X)^M} - 1$$

where

y = percent of vehicles left in service
X = vehicle age, in years

This equation is uniquely determined by five constraints. The first constraint is the normalized value of 1972 total vehicle population distribution by model year (1957 through 1972) as derived from Table 8-12 and R. L. Polk Company registration data by model year.

The second constraint is the ratio of 1970 new vehicle registrations to 1957 vehicles left in service, corrected by the 1970 to 1957 new vehicle registration ratio. The result is the percentage of vehicles still in service after 15 years of use.

The third constraint is the normalized value of vehicles older than 1957 still in service in 1972.

The fourth constraint is the assumption that practically no vehicles are left after 25 years of service. (Actual results show a decay period of 20 years for passenger cars and 25 years for all trucks.)

The fifth constraint is:

$$e^{-C_1(15)^N} = e^{C_2(10)^M} - 1$$

which says that both parts of the equation must have the same coordinates at 15 years of age. Hence, the equation $y = e^{-C_1 X^N}$ describes the attrition factor for the age bracket 0 to 15 years, and the equation $y = e^{C_2(25 - X)^M} - 1$ describes the attrition factor for vehicles older that 15 years. These attrition factors were determined for the period 1947 to 1972. However, examination of the data shows little change in the attrition factor over the years; therefore, a single attrition factor was used for the period extending to 1990.

Finally, the total number of vehicles calculated for a given AQCR were forced to agree with the vehicle population given in Table 8-12 for that AQCR, by using a multiplier factor. This multiplier corrects for normalizing values based on insufficient registration data breakdowns.

E. 2 VEHICLE MILEAGE DETERMINATION

The mileage distribution according to vehicle age was based on the normalized average miles driven values of Tables 10 and 16 of Ref. E-1. However, the magnitude of the mileage distribution function was adjusted to result in the total miles traveled values for each AQCR as shown in in Table 8-12.

E. 3 EMISSION CORRECTION FACTORS

Specific LDV, MDV, and HDV emission characteristics by model year and deterioration-with-age factors used were delineated in Section 9. Deterioration-with-age factors were applied only to passenger cars and light-duty trucks (LDV class). No velocity corrections were used in any of the emission calculations (speed correction factor = 1.0).

REFERENCES

E-1. D. S. Kircher and D. P. Armstrong, An Interim Report on Motor Vehicle Emission Estimation, EPA (October 1972).

E-2. Statistical Abstract of the United States, 1972, U. S. Department of Commerce, Bureau of the Census

GLOSSARY

AQCR	Air Quality Control Region
CID	cubic inch displacement
CO	carbon monoxide
CVS	constant volume sampling
DF	degradation factor
ECS	emission control system
EGR	exhaust gas recirculation
EVW	empty vehicle weight
FDC	Federal Driving Cycle
FGR	flue gas recirculation
FTP	Federal Test Procedure
gm	gram
gm/mi	gram per mile
GVW	gross vehicle weight
HC	hydrocarbon
HDV	heavy-duty vehicle (over 14, 000-lb GVW)
I_w	inertial test weight
LDV	light-duty vehicle (under 6000-lb GVW)
MDV	medium-duty vehicle (6, 000 to 14, 000-lb GVW)
mpg	miles per gallon
NO_x	oxides of nitrogen

SARR	San Antonio Road Route
SCAB	South Coast Air Basin (Los Angeles)
VMT	vehicle miles traveled
W_c	curb weight
W_{test}	test weight